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NAVIGATION, GUIDANCE, and CONTROL

OAST Summer Workshop

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National Aeronautics and Space Administration
Office of Aeronautics and Space Technology and Old Dominion University

Vol. III of XI

NOTICE

The results of the OAST Space Technology Workshop which was held at Madison College, Harrisonburg, Virginia, August 3 - 15, 1975 are contained in the following reports:

EXECUTIVE SUMMARY

VOL I DATA PROCESSING AND TRANSFER

VOL II SENSING AND DATA ACQUISITION

VOL III NAVIGATION, GUIDANCE, AND CONTROL

VOL IV POWER

VOL V PROPULSION

VOL VI STRUCTURE AND DYNAMICS

VOL VII MATERIALS

VOL VIII THERMAL CONTROL

VOL IX ENTRY

VOL X BASIC RESEARCH

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Office of Aeronautics and Space Technology

Summer Workshop

August 3 through 16, 1975

Conducted at Madison College, Harrisonburg, Virginia

Final Report

NAVIGATION, GUIDANCE AND CONTROL PANEL

Volume III of XI

OAST Space Technology Workshop

NAVIGATION, GUIDANCE, AND CONTROL PANEL

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SUMMARY OF THE FINAL REPORT OF THE NAVIGATION, GUIDANCE AND CONTROL WORKING GROUP

OAST WORKSHOP AUGUST 1975

The NGC working group collected "user" technology requirements based on the outlook for space and certain user groups such as OSS, OA, and OMSF. These user requirements were compared with technology requirements generated prior to the workshop. New technology requirements were subsequently developed and revisions and modifications of existing technology requirements were made in light of user needs.

The user requirements were then grouped into three major thrusts. These major thrusts provide a blanket for related technology advancement or imporvement and support several of the NASA user offices. These major thrusts are:

1. REDUCE MISSION SUPPORT COST BY 50% THROUGH ANTONOMOUS OPERATION BY 1990,
2. PROVIDE A TEN-FOLD INCREASE IN MISSION OUTPUT THROUGH IMPROVED POINTING AND CONTROL BY 1990, AND
3. PROVIDE A HUNDRED-FOLD INCREASE IN HUMAN'S PRODUCTIVITY IN SPACE THROUGH LARGE-SCALE TELEOPERATOR APPLICATIONS BY 1990.

In all, forty-seven technology requirements were identified that support user requirements. General emphasis could be identified under each of the three major thrusts. These are

Autonomous Operations
- Long Life Components and Systems.
- Antonomous Spacecraft and Systems.
- Self-Repairing Spacecraft Systems.
- Automated G & C Electronics
- Long Life Time Reliability Assurance.

Pointing and Control
- Large Arrays and Structures.
- Interplanetary Instrument Pointing.
- Earth Orbital Pointing Altitude Control.
- Precision Instrument Pointing for Manned Missions.

Teleoperators

In-Space Construction Techniques
Orbital Assembly Maintenance, Repair
Remote Controlled Manipulators.

Next, the technology requirements were reviewed to determine if they could benefit from a shuttle flight experiment. A total of fifteen were identified that could benefit from a flight test. Some of the future payload technology space tests require or are enhanced by the space environment, while others benefit from a systems test, required for user acceptance, that can only be performed meaningfully in space. In some cases it appeared that one Shuttle flight might be able to accommodate several experiments in a single flight experiment package. Two of these packages are:

1. Inertial Components Test Facility including low-g accelerometer experiments and redundant strapdown Inertial Measurement United experiments, and

2. Modular Instrument Pointing Test Facility including experiments related to optical and video correlator landmark trackers and the Video Inertial Pointing System for Shuttle Astronomy Payloads.

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FINAL REPORT

NAVIGATION, GUIDANCE AND CONTROL

I. INTRODUCTION

A. WORKING GROUP APPROACH

The Navigation, Guidance and Control working group consisted of eight members:

Mr. William D. Bachman, Chairman (JPL)
Mr. Kirk M. Dawson (JPL)
Dr. William B . Gevartar (OAST, HQTRS)
Mr. Harold J. Gordon (JPL)
Mr. William D. Hibbard (GSFC)
Mr. William E. Howell (LARC)
Mr. J. Dwight Johnston (MSFC)
Mr. James P. Murphy (ARC)

In addition to the committee members, the Working Group was greatly aided by Dr. W. Jack Breedlove and Dr. Ping Tcheng from Old Dominion University who functioned as Collaborators with the Group.

In order to increase the productivity of the Working Group and allow the members to work in areas of their primary specialties, the Group was divided into three subgroups as shown in Figure 1. Although during most of the proceedings the Working Group functioned as a single unit, there were times when the three subgroups operated independently to generate material.

The steps that the working group followed in developing recommended shuttle payloads are shown in Figure 2. User requirements were developed form the material presented by the Workshop User Working Group and reported in the Outlook for Space Report. Once generated, these requirements were reviewed by the User Working Group to determine if all pertinent needs had been identified. After the re requirements had been identified and checked they were grouped into three major thrusts which provided a framework for later discussions.

The next major step in the process was to review the technology requirements generated in advance and brought to the workshop by the NG&C Working Group members. These were studied in light of the user requirements, deficiencies and omissions were noted and new technology requirements were generated where necessary. Several technology requirements were found to be related to other working group's responsibilities and this material was forwarded to those groups.

Once the technology requirements were completed, they were individually reviewed to determine if they could benefit from a shuttle flight experiment. Finally, the experiments that were derived from this process were grouped into related categories. In some cases, it appeared that one Shuttle flight might be able to accommodate several experiments in a single flight experiment package

The last two boxes on the lower right of Figure 2 represent an activity not directly related to identifying Shuttle experiments but definitely important to OAST programs in Navigation, Guidance and Control. Identification of desirable new starts was the prime objective of this comparison.

W. E. BACHMAN

CHAIRMAN

NAVIGATION & GUIDANCE	CONTROL	TELEOPERATORS/ROBOTICS
(Lead) Bill Howell - LaRC	(Lead) Jim Murphy - ARC	(Lead) Kirk Dawson - JPL
Hal Gordon - JPL	Bill Gevarter - Hdgtrs	Dwight Johnston - MSFC
Kirk Dawson - JPL	Bill Hibbard - GSFC	Bill Bachman - JPL

Figure 1. Navigation, Guidance and Control Subgroup Organization

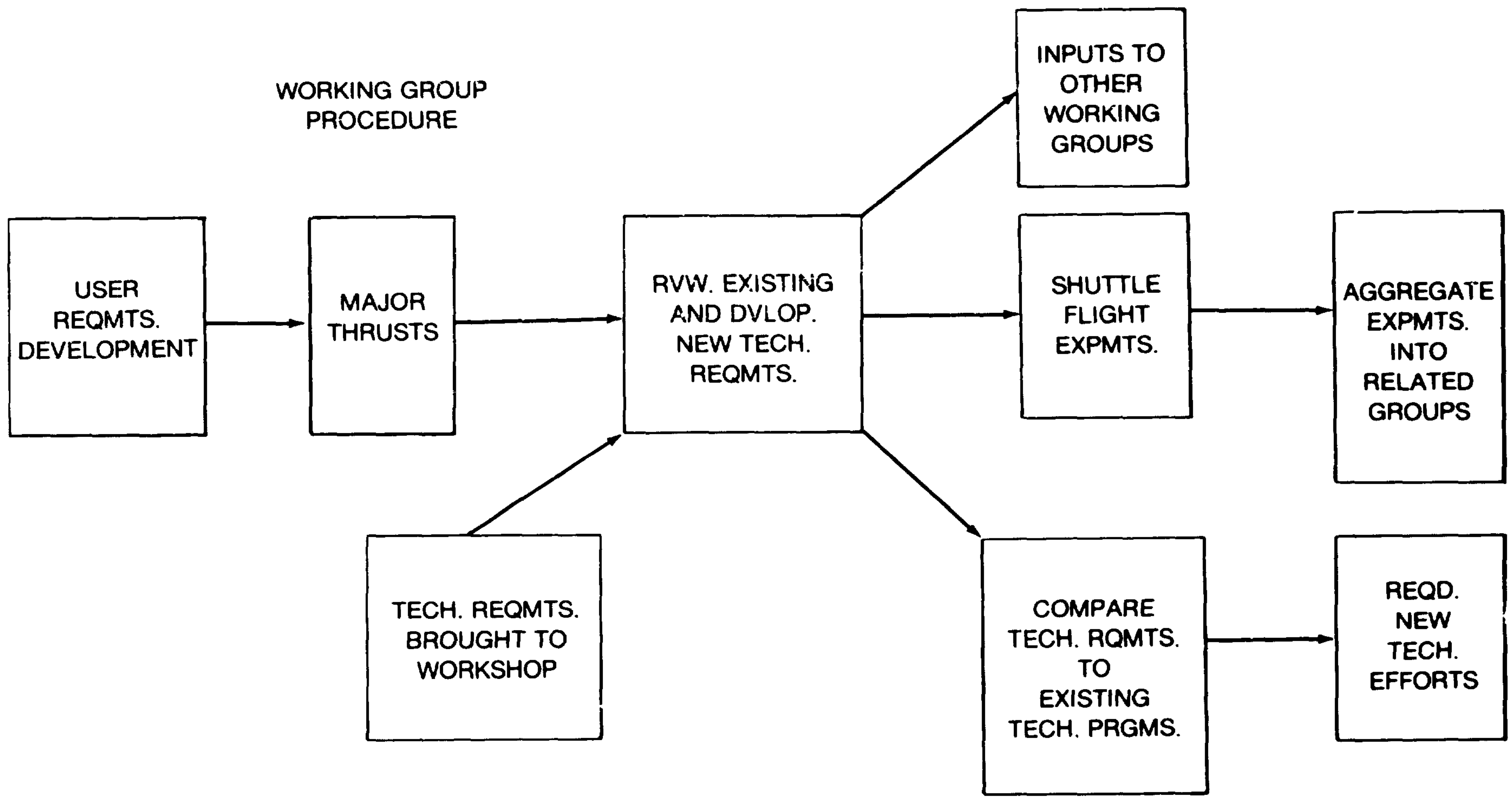


Fig. 2: NAVIGATION, GUIDANCE & CONTROL
WORKING GROUP PROCEDURE

NGC-2

II. USER REQUIREMENTS

A. INPUTS FROM USERS

User requirements were provided in the form of a written input in the 1975 NASA OAST SUMMER WORKSHOP OVERVIEW REPORT. These written inputs were supplemented by a series of presentations to the workshop. The written inputs were provided by each of the NASA user offices and were supplemented by verbal discussions during the workshop between the Navigation, Guidance and Control Working Group and the Users Workshop Group. User requirements were then generated for each of the NASA program offices.

B. OUTLOOK FOR SPACE

User or mission requirements were also derived from the Outlook for Space Report, A Forecast of Space Technology, Section V. The forecasts presented in the report were correlated with the User Input requirements to obtain more quantitative data relating to the user requirements.

C. MAJOR THRUSTS AND TECHNOLOGY NEEDS

When the user requirements were examined it became apparent that they could be grouped into three major thrusts in the navigation, guidance and control disciplines that require major effort to support the user requirements. These major thrusts provide a blanket for related technology advancement or improvement and support several of the NASA user offices. The major thrusts and associated user requirements are listed below:

1. REDUCE MISSION SUPPORT COST BY 50% THROUGH AUTONOMOUS OPERATION BY 1990

   *Develop long life, self-repairing spacecraft systems

   *Provide automated rendezvous and docking systems and techniques

   *Develop guidance and control systems for near-automated long mission use

   *Improve the position knowledge of orbital and deep space systems

   *Develop autonomous unmanned lunar and planetary rovers with emphasis on mobility, articulation, guidance, navigation and control systems

2. PROVIDE A TEN-FOLD INCREASE IN MISSION OUTPUT THROUGH IMPROVED POINTING AND CONTROL BY 1990

   *Develop pointing and control for large structures and arrays

   *Improve instrument pointing and spacecraft attitude control for unmanned interplanetary vehicles

   *Develop precision instrument pointing for manned earth orbital vehicles

3. PROVIDE A HUNDRED-FOLD INCREASE IN HUMAN'S PRODUCTIVITY IN SPACE THROUGH LARGE-SCALE TELEOPERATOR APPLICATION BY 1990

   *Develop and provide means of remotely monitoring, inspecting, and collecting visual data during deployment, retrieval, structure assembly, etc., to verify activities not normally visible.

   *Develop capability for deployment, retrieval, servicing and assembly of payloads, large space structures, lunar bases, etc., with earth orbital and surface type vehicles.

   *Provide a transporter for transfer of materials, tools, and crew in support of EVA activities.

III. ADVANCED TECHNOLOGY REQUIREMENTS

A. INTRODUCTION

Technology requirements were derived from two sources. The first source involved inputs, prior to the workshop, by members of the working group based on inputs from the respective centers and the individuals knowledge of future program requirements. In addition to these technology requirements, additional requirements were formulated by the working group as a whole based on the user inputs to the workshop and the outlook for Space Study. These technology requirements fall naturally into the major thrust areas that were identified and are listed in resume form in Section III-B and in full form in Section III-C.

B. TECHNOLOGY REQUIREMENTS RESUMES

1. LOW COST NAVIGATION INDEPENDENT OF NASA TRACKING FACILITIES

There exists several wide-spread navigation nets for aircraft use around the world. The most notable are DME and OMEGA. The first operates at UHF with power in the one to twenty KW range. This frequency and power is more than adequate for reception from spacecraft altitude. The second operates with high power, is worldwide, but is in the VLF band. However, it may be useable. At this time there has been no adequate survey of the signal strength of earth based navigation aids at orbital spacecraft altitudes. This work would propose an experiment to fly high quality aircraft navigation gear (receiver/transmitter) to determine the possibility of designing future earth orbital satellites with the capability of doing their own navigation, thus reducing mission support requirements.

2. APPROACH GUIDANCE FROM A SPINNING SPACECRAFT

Approach guidance measurements require an extremely stable spacecraft platform and extremely accurate angular measurements of point sources and extended objects. Current spinning spacecraft do not have sufficient spin stability to allow accurate angular movements.

3. SCANNING LASER RADAR

Scanning laser radars are presently designed to use either Carbond Dioxide (CO_2) or Gallium Arsenide (Ga As) as the laser source. The concept requires no moving parts, requires low power and can proved range, range rate, angle and angular rate as a navigational aid to a manned rendezvous and docking system. Where retro-reflectors are utilized it provides a means for autonomous control.

4. DEVELOPMENT OF LOW COST NAVIGATION COMPONENTS

Present efforts to develop low cost inertial systems are hampered by the fact that many present day components were developed with performance as the prime goal and cost secondary. In doing this many inherently cheaper concepts have been discarded because they lacked the potential for performance refinement. There are many applications today which require modest accuracy, but very low cost to make then economically feasible. What is required is an unified, directed attempt to provide funding for new concepts (as opposed to improvements in old designs) which show promise for geuine cost benefits.

5. AUTONOMOUS GUIDANCE AND NAVIGATION

This new technology consists of development of an on-board capability to automatically collect observations using an optical sensor, and process that data to determine the S/C orbit, subsequently making a trajectory correction maneuver in an optimal manner and/or adjusting or modifying a pre-planned science sequence. This capability can later be expanded to include detecting targets-of-opportunity and modifying the trajectory to investigate or avoid them. Certain missions, such as those requiring decision reaction times shorter than the round-trip light time, could not be done in any other way.

6. DIFFERENTIAL VERY LONG BASELINE INTERFEROMETRY (ΔVLBI) and PULSAR NAVIGATION

ΔVLBI measurements consist of interferometrically tracking S/C and an extragalactic source, which allows S/C target-relative coordinates to be fixed in an intertial coordinate system. When the S/C flies by, orbits, or lands on the target planet/satellite its ephemeris can be significantly improved, decreasing a limiting error source for future missions.

Flight equipment must be developed to locate and record signals from pulsars. These recordings, with accurate time tags, would then be compared to similar pulsar recordings made on the earth. The correlation between these recorded signals allows S/C position determination accuracy that is indpendent of the S/C-Earth distance. An alternative technique would be to have a catalog of characteristics on the spacecraft and perform the correlation autonomously.

7. COMET AND ASTEROID EPHEMERIDES IMPROVEMENT

A dedicated and systematic observation schedule, including radar bounce data, would allow improved small body ephemerides to be developed. This would enable comet or asteroid missions to be designed in a timely manner. For very uncertain ephemerides, the spacecraft would have to be launched on a trajectory that had the ability to be significantly adjusted as observation data accumulated (both earth-based and S/C based when approaching the target body).

8. COMETARY INTERCEPT NAVIGATION AND GUIDANCE

Cometary ephemerides are very poorly known, and in fact change from one appearance to another for the periodic comets. Most of the comets known to date appear to be on parabolic orbits and have been first discovered within 6 to 10 months of their perihelion. A cometary intercept mission to a newly discovered comet having a poorly defined trajectory is possible if launched as early as possible on a high energy trajectory which can be corrected until the intercept occurs. This implies development of a high-energy probe capability and the development and mechanization of an optimal navigation strategy.

9. AUTOMATED SPACECRAFT

The objective of this task is to develop the technology necessary to increase the capability of spacecraft to perform complex, self-contained tasks. This is a summary technology requirement description including the development areas of; the structure of the control elements, the process of decision-making (problem solving), interaction between the spacecraft and human controller, techniques for controlled manipulation and roving vehicle control.

10. ROBOTIC DECISION MAKING AND PLANNING

This task develops the capability for a robotic system to plan and implement a task or series of tasks once a high level supervisory command statement has been sent to the robot. Decision-making and planning are functions that human beings perform rather effortlessly and well, but very little is known about how to automate them. There is strong desire to make robot machines independent of earth-based surveillance and to free the ground personnel for other tasks.

11. ROBOTIC SCENE ANALYSIS

For a robot to operate autonomously it must develop a model of its surroundings. This model, located in the robot's computer, will allow safe movement from place to place and permit the carrying out of commanded functions (pick up a rock located a a specific location, etc.). Scene analysis, which is closely related to the function of perception, involves computer dissection of pictures, combination of this data with other sensory data from instruments such as laser range finders and construction of a "world model". This model is continually updated and corrected as the robot moves in carrying out its tasks.

12. END EFFECTOR SENSORS FOR ROBOT AND TELEOPERATOR MANIPULATORS

Various types of sensors can be used on end effectors of remote manipulators to speed up and/or automate the manipulation process. Touch sensors, force feedback sensors, optical promimity sensors and various pressure sensors can be used for this purpose. The presentation format of this data to the teleoperator operator or to the robot computer and how this data should be interpreted and used by the operator and computer are major technology problems being worked by this task.

designs and to provide verification of design equations and procedures. This is an alternate procedure to that proposed by the "STS advanced systems technology guidance and control working group", January 1974. In that document a new ground based facility was recommended.

19. HIGH RESOLUTION LONG LIFE INERTIAL REFERENCE UNIT

To broaden the applicability of the dry (tuned-rotor) gyro inertial reference unit (DRIRU) by increasing the fine pointing capability, the development of higher resolution loop electronics and an improvement in the gyro motor bearing configuration is required. Pointing stability of 1 arc second for periods up to one hour is required.

20. CRYOGENIC GYROSCOPES FOR SPACE AND AIRCRAFT NAVIGATION

An extremely low drift, electrostatic gyro, with cryogenic pick-off, is being developed for a science experiment. Its low drift rate of 10^{-9} radian per year would be of grat value to a wide variety of earth and interplanetary missions because it eliminates the need for external sensing of a attitude. The technology is anticipated by the early 1980's.

21. CONTINUED DEVELOPMENT OF DIGITAL REBALANCE ELECTRONICS FOR DRY TUNED ROTOR CYROS

A rebalance electronics package will provide digital torque control and substantially improve the accuracy and resolution over the current analog electronics.

22. HIGH RESOLUTION ATTITUDE SENSOR

A high resolution attitude sensor is required for missions such as LST. The laser gyro is a promising candidate. (Cf. Laser Rate Gyro Package)

23. LOW G ACCELEROMETER EVALUATION FACILITY

The measurement of spacecraft acceleration to levels of 10^{-9} g and lower require a very stable and low noise test platform.

13. <u>UNASSIGNED</u>

14. <u>STELLAR II (STARTRACKER)</u>

Develop an internally redundant, radiation-hardened and fault tolerant CCD star tracker. This task is an outgrowth of the STELLAR star tracker now under development.

15. and 16. <u>INTENSIFIED SOLID STATE IMAGING DEVICE AND CHARGE INJECTION DEVICE FOR LOW LIGHT LEVEL IMAGING</u>

The abstracts for these two technology requirements are summarized into one.
The existing technology demonstrates the need and potential for increasing the sensitivity of "charge injection devices" (CID) imaging devices. Such a method provides a second generation of solid state devices.
Due to ruggedness, small size, low weight and power consumption these devices will be strong competitors to the low light level tube type system.
Improvements to the existing CID technology in the areas of resolution, sensitivity, uniformity sizing and selection will allow it to be used for the sensor in solid state star trackers.

17. <u>OPTICAL STANDARDIZATION AND IMPROVED TUBE DESIGN FOR STAR TRACKERS</u>

Proper utilization of present day technology permits a modification of the internal parts of the image dissector tube that can greatly improve its performance in star trackers.
Development of a standard lens for the image dissector tube will meet the star tracker needs until solid state devices (such as CID's and CCD's) can be developed into flight worthy systems.

18. <u>STRAY-LIGHT REJECTION</u>

It is extremely difficult and expensive to evaluate stray light attenuators (sun and earth shades) in earth based facilities. One reason is that test facility walls scatter light from the solar simulators. This makes verfication of new designs difficult. Shuttle sortie flights provide an opportunity to evaluate the attenuation qualities of new sun shade

24. RATE GYRO PACKAGE

The laser rate gyro currently under development offers an alternative to the inertial rateintegrating gyro that should prove less expensive and less vulnerable to ambient acceleration. Successful demonstration of the laser gyro will provide a cost beneficial alternative to the inertial gyro.

25. REDUNDANT STRAPDOWN LASER INERTIAL MEASUREMENT UNIT (IMU) FOR SPACE MESSIONS

The Tug will require an IMU for self-contained guidance for orbit change and as an attitude reference. Laser IMU should be simpler, lighter in weight, more reliable and less costly than conventional systems. A Shuttle payload will flight qualify the IMU for Tug and longlife space missions.

26. OPTICAL CORRELATOR LANDMARK TRACKER

One of the major applications of space is to survey, monitor and service earth and its inhabitants. There is a major need for a device which can pick out an arbitrarily chosen target on the earth and provide an accurate earth-pointing error signal. The optical correlator landmark tracker has this potential. To accomplish this, it utilizes pattern recognition in the spatial frequency domain to provide the pointing signal. This device is functionally related to the video landmark tracker below, however, the technical aspects of the two systems are significantly different.

27. VIDEO CORRELATOR LANDMARK TRACKER

This device is aimed at fullfilling a similar technology requirement as the optical correlator landmark tracker. However, the technical aspects of achieving the ultimate goal is significantly different. This device relies on software processing of video data and algorithm development to recognize selected points. Because of the desirability of using landmark tracking, alternate technology approaches are essential.

28. OPTICAL INERTIAL REFERENCE

This technology requirement proposes the development of an optical inertial reference incorporating a laser/fiber optics rotation sensor. A small laser is coupled to each end of a fiber optic strand wound in a coil on a small mandrel. Rotation about the axis of the coil alters the relative frequencies of light passing through the fiber with, and against, the direction of rotation. Mixing and beat detection provide a direct digital measurement of rotation rate.

29. UNASSIGNED

30. HARD LANDER CONTROL SYSTEM FOR AIRLESS PLANETS

Penetrators rely on control of impact angle of attack to ensure survival of the scientific instruments. For missions to airless planets or the moon, aerodynamics cannot be used, and an active system must be developed to control the impact angle of attack.

31. VIDEO INERTIAL POINTING SYSTEM FOR SHUTTLE ASTRONOMY PAYLOADS

Pointing at non-visible or dim astronomy targets require tracking members of the adjacent star field. Since the position of many dim targets is not precisely known with respect to the star field, the ability to view the adjacent field and complete the acquisition with an operator is crucial to the success of many astronomy missions. A video sensor can be used to provide multi-star position data for three axis pointing error signals and information for a CRT display of the star field.

32. ATTITUDE CONTROL OF FLEXIBLE SPACECRAFT CONFIGURATIONS

Instrument pointing from a flexible structure typical of manned, earth resource and planetary spacecraft of the future need control systems capable of filtering the motions caused by the flexibility of the main spacecraft. On-going work (RTOP 506-19-14) will develop the initial tools for incorporating a realistic non rigid vehicle model into the design of a stochastic controller by 1979. A non flight critical control system, preferably programmable, designed with control algorithms based on dynamical models of the supporting structure would provide a practical demonstration of the new analytical tools. Alternately a complete flight evaluation of the structure control, attitude control and the pointing control could be performed on a early prototype structure for an on-going mission. This would qualify the technology and the operational components simultaneously.

33. FIGURE CONTROL OF LARGE DEFORMABLE STRUCTURES

Figure or shape control of large flexible structures which emit or collect electromagnetic radiation is necessary to maintain efficiency and high gain for increased bandwidth and resolution. To provide shape control to fractions of a wavelength in the operating frequency region of interest will require advances in structural modeling and the technology of sensors and actuators.

34. HIGH ACCURACY INSTRUMENT POINTING SYSTEM FOR FLEXIBLE BODY SPACECRAFT

Future planetary and comet missions require science instrument pointing capability that current Mariner/ Viking class articulation control systems cannot satisfy. The approach to advancing the science instrument pointing system is to develop an instrument pointing platform control system having a fast response inertially stabilized instrument line of sight.

35. SPACECRAFT SURFACE FORCE CONTROL(SURFCON) AND ATTITUDE CONTROL SYSTEM

There is a class of future planetary and solar probe missions that requires the spacecraft to follow a purely gravitational trajectory for highly accurate relativistic, gravimetric and atmospheric physics measurements. These science requirements cannot be satisfactorily met by current spacecraft attitude and translation control system designs. This requirement can be met with a Mariner class attitude control system that compels the spacecraft to center on a spherical proof-mass in the translational degrees of freedom. This concept has been flight proven on Navy Transit Satellites for earth orbital application.

36. RADIATION ATTITUDE CONTROL FOR EXTENDED LIFE PLANETARY MISSIONS

During interplanetary flight, radiation from RTG's impinging on vehicle structure is usually a primary disturbance torque to attitude control. There exists a possibility of using these forces as a control torque with the possibility of significant savings in expendibles. A program is required to study the nature, magnitude, and variation of RTG radiation for the purpose of there axis stabilization.

37. FLUID MOMENTUM GENERATOR

The Fluid Momentum Generator provides a jitter-free alternative to the conventional ball-bearing reaction wheel. Fluid M/G's have been demonstrated successfully, but they consumed excessive power because of the high fluid friction. The proposed development would investigate the use of magnetic fluids to obtain a high density, low viscosity fluid that could be efficiently driven by a linear motor. The result would be an alternate choice to the magnetically suspended reaction wheel, offering lower complexity and cost.

38. MEASUREMENT AND CONTROL OF LONG BASELINE STRUCTURES

Technology must be provided for accurate interferometric measurement. These measurements require precise knowledge and stability of long base line structure. Their structure may or may not be physically connected; therefore, a variety of control techniques and measurement methods must be used. This technology requirement is related to that of figure or shape control of large structures, but has several unique requirements which need special attention, i.e., potential for disconnected structures.

39. MAGNETIC LARGE ARRAY ASSEMBLY AND SHAPE MANAGEMENT

There exists a technology requirement for large light weight arrays for sensors and antennas in space with tightly controlled contours. One possibility to do this is to employ modular arrays magnetically coupled and controlled. This requires further exploration as to feasibility and practicability.

40. UNASSIGNED

41. SPACE TELEOPERATOR TECHNOLOGY

The requirement for this activity and the related technology requirements (42 through 50) is to define and develop experimental and prototype teleoperator systems for earth, lunar and planetary orbit and surface operations. Teleoperator systems offer great potential for doing this. Functioning as extensions of spacecraft, as free flying vehicles operated form the shuttle, space station, or the gound; or as surface vehicles remotely operated from earth, the teleoperator will augment the human in performing a number of useful tasks which otherwise would not be possible.

42. SUPERVISORY CONTROL OF REMOTE MANIPULATORS

Requirements exist to develop optimum man-machine interface technologies for controlling manipulators when computers are part of the supervisory control loop. Efficient, versatile and safe control performance of remote manipulation dpends to a great extent on the allocation of control functions between operator and control computer.

43. SATELLITE SERVICING

Requirements exist to develop optimal interface hardware conceptual designs to enhance satellite servicing capabilities and verify these concepts and designs using in-orbit experiments.

44. MULTI-PURPOSE PANEL

Requirements exist to devehop an addressible alphanumeric display for flight and ground based control and display stations which will permit rapid changes in panel nomenclature and control outputs.

45. END EFFECTORS AND SENSORS

End effectors, that part of the manipulation that actually conducts the grasping or is involved with target object needs continued development. Both special purpose and general purpose effectors and associated sensors are needed.

46. TELEOPERATOR CONTROLLERS

The technology of controllers for teleoperators is key to mans effective interaction with the machine. The flexibility of this control, the response time of control and the human engineering aspects are all important factors that must be advanced

47. WRIST MECHANISMS

One key element of a manipulator is the wrist mechanism that attaches to the end effector. The flexibility and versatility of this item is central-along with the end effector itself- to effective manipulator operation.

48. MINIATURE TV CAMERA

Extremely small, manipulator mounted, T.V. cameras would greatly aid the operator in obtaining a realistic "sense of presence". The requirement for this type of TV instrument will be pursued further with appropriate sensor people.

49. IMAGE ENHANCEMENT

The enhancement of T.V. images presented to the operator-contrast enhancement, low and high level light exposures, etc., are necessary to handle the varied imaging conditions in space. Computer control of the enhancement process will provide great versatility.

50. VIDEO SIGNAL COMMUNICATIONS

Teleoperations using sophisticated T.V. displays for presenting information to the operator require high data rates and large bandwiths. There are many advantages for the overall Teleoperator system if technological "shortcuts" and advances can be conceived for getting the required information to the operator at reduced communications channel requirements.

C. TECHNOLOGY REQUIREMENTS FORMS

The following are the 50 Technology Requirement forms generated as part of the Navigation, Guidance and Control Working Group activities.

I. Autonomous Operation of Spacecraft

1. Low Cost Navigation Independent of NASA Tracking Facilities
2. Approach Guidance from a Spinning Spacecraft
3. Scanning Laser Radar
4. Development of Low Cost Navigation Components
5. Autonomous Guidance and Navigation
6. Differential Very Long Baseline Interferometry (VLBI) and Pulsar Navigation
7. Comet and Asteroid Ephemerides Improvement
8. Cometary Intercept Navigation and Guidance
9. Automated Spacecraft
10. Robotic Decision Making and Planning
11. Robotic Scene Analysis
12. End Effector Sensors for Robot and Teleoperator Manipulators
13. Unassigned

II. Sensors

14. Stellar II (Star Tracker)
*15. Intensified Solid State Imaging Device
*16. Charge Injection Device for Low Light Level Imaging
17. Optical Standardization and Improved Tube Design for Star Trackers
18. Stray-Light Rejection
19. High Resolution Long Life Inertial Reference Unit
*20. Cryogenic Gyroscopes for Space and Aircraft Navigation
21. Continued Development of Digital Rebalance Electronics for Dry Tuned Rotor Gyros
22. High Resolution Attitude Sensor
23. Low-g Accelerometer Evaluation Facility
24. Rate Gyro Package
25. Redundant Strapdown Laser Inertial Measurement Unit (IMU) For Space Missions
26. Optical Correlator Landmark Tracker
27. Video Correlator Landmark Tracker
*28. Optical Inertial Reference
29. Unassigned

B. Systems and Components

30. Hard Lander Control System for Airless Planets
31. Video Inertial Pointing System for Shuttle Astronomy Payload
32. Attitude Control of Flexible Spacecraft Configurations
33. Figure Control of Large Deformable Structures
34. High Accuracy Instrument Pointing System for Flexible Body Spacecraft
35. Spacecraft Surface Force Control (SURFCON) and Attitude Control System
36. Radiation Attitude Control for Extended Life Planetary Missions
*37. Fluid Momentum Generator
38. Measurement and Control of Long Baseline Structures
39. Magnetic Large Array Assembly and Shape Management
40. Unassigned

III. Teleoperators

41. Space Teleoperator Technology
42. Supervisory Control of Remote Manipulators
43. Satellite Servicing
44. Multi-Purpose Panel
45. End Effectors and Sensors
46. Teleoperator Controllers
47. Wrist Mechanisms
48. Miniature TV Camera
49. Image Enhancement
50. Video Signal Communications

* Referred to other working groups

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 1

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 3

Low Cost Navigation Independent of NASA Tracking Facilities

2. TECHNOLOGY CATEGORY: Navigation

3. OBJECTIVE/ADVANCEMENT REQUIRED: To investigate the potential use of earth based navigation aids such as DME, OMEGA, etc., for use from earth orbit.

4. CURRENT STATE OF ART: No comprehensive survey of signal strength or propagation characteristics of these sources has been made.

HAS BEEN CARRIED TO LEVEL 6

5. DESCRIPTION OF TECHNOLOGY

There exists several wide spread navigation nets for aircraft use around the world. The most noteworthy are DME and OMEGA. The first operates at UHF with power levels of one to twenty kw. This frequency and power level is more than adequate for reception from spacecraft altitudes. The second operates with high power, is world wide, but is in the VLF band. However, it may be useable. At this time there has been no adequate survey of the signal strength of earth based navigation aids. There has been a proposal to monitor these from space for maintenance purposes.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Many satellites require only modest navigation data or orbit determination data in order to perform broad surveys or station keeping missions. To meet these requirements it is necessary for ground based facilities to acquire, track, and determine orbital parameters. This requirement at times leads to conflicts when two or more satellites require simultaneous servicing. If the data from ground based navigation aids is useful, it may be possible for the satellite to provide its own on-board navigation with occasional checks from ground stations. Aircraft can get accuracies to 200 feet from these systems. Commensurate accuracies in near earth orbit could be expected with some degradation at higher orbits.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 1

1\. TECHNOLOGY REQUIREMENT(TITLE): PAGE 2 OF 3

Low Cost Navigation Independent of NASA Tracking Facilities

7\. TECHNOLOGY OPTIONS:

Present tracking is adequate, but may become overloaded when the STS makes satellite launches cheaper and hence increases the number of satellites.

8\. TECHNICAL PROBLEMS:

Propagation characteristics are unknown, available signal strength, and useful frequencies are also unknown.

9\. POTENTIAL ALTERNATIVES:

Autonomous navigation using other techniques, which may or may not be as cheap.

10\. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

No advances anticipated unless planned survey missions turn up unexpected results. Such a pontential use as this may serve to justify and direct initial surveys.

EXPECTED UNPERTURBED LEVEL 6

11\. RELATED TECHNOLOGY REQUIREMENTS:

Development of space qualified components similar to that used in aircraft.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 3

1 TECHNOLOGY REQUIREMENT (TITLE): PAGE 3 OF 3

Low Cost Navigation Independent of NASA Tracking Facilities

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Initial Studies																			
2. Design of Equipment for Survey flight																			
3. Fabrication of Equipment																			
4. Survey Flight																			
5. Operational Equipment Design																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE									X									
NUMBER OF LAUNCHES						UNKNOWN												

14 REFERENCES:

Comments and Observations:

1. Determine if this idea has been investigated before.
2. Coordinate this idea with other agencies such as FAA.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 2

1 TECHNOLOGY REQUIREMENT (TITLE): Approach Guidance from a Spinning Spacecraft PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Guidance and Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase accuracy and stability of sensors and spacecraft to achieve precise measurements from spinning spacecraft.

4. CURRENT STATE OF ART: Earth orbiting spacecraft have included star and horizon sensors.

HAS BEEN CARRIED TO LEVEL 7

5. DESCRIPTION OF TECHNOLOGY

Approach guidance measurements will require an extremely stable spacecraft platform and extremely accurate angular measurements of point sources and extended objects. Current spinning spacecraft are not designed for extreme spin stability. Current sensors cannot accurately measure the position of extended objects.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☒ A, ☐ B, ☐ C/D

6 RATIONALE AND ANALYSIS:

a. Spacecraft platforms must be stable to 20-30 micro rad. during approach guidance measurements. Measurements must be performed during approach to Uranus and Titan at distances where the target is an extended object.

b. Pioneer Uranus Entry Probe, Pioneer Titan Probe Missions.

c. Without approach guidance, probe targeting must be based on existing Ephemeris predictions, which are not accurate enough to assure safe entry.

d. Sensor accuracy can be demonstrated by analysis and lab tests. Spacecraft stability must be demonstrated by simulation.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 2

1. TECHNOLOGY REQUIREMENT(TITLE): Approach Guidance from a Spinning Spacecraft PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

8. TECHNICAL PROBLEMS:

Sensor which achieves 50 micro rad. accuracy while measuring extended objects.

Spacecraft design approach to achieve 30 micro rad. stability to spin axis.

9. POTENTIAL ALTERNATIVES:

Improvement of Ephemeris of Uranus and Titan would allow Earth-based radio guidance to be used for Probe targeting.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 2

1 TECHNOLOGY REQUIREMENT (TITLE): **Approach Guidance From a Spinning Spacecraft** PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis																			
2. Design																			
3. Simulation																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE						Δ												
NUMBER OF LAUNCHES									1	1	1							3

14 REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 3

1. TECHNOLOGY REQUIREMENT (TITLE): Scanning Laser Radar PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Guidance Control and Stabilization

3. OBJECTIVE/ADVANCEMENT REQUIRED: To develop a scanning laser radar for rendezvous and docking in space. Determine the design requirements and investigate possible laser sources.

4. CURRENT STATE OF ART: Carbon Dioxide (CO_2) and Gallium Arsenide (GaAs) laser sources are being considered.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

A design of concept of CO_2 laser radar is in progress. Studies are concentrated on performance improvements, lower power demands, and suitable material to be used for the reflective optics. GaAs material is being studied and being weighed against CO_2 as a laser source. Applicable supporting electronics is under study, design and test.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☒ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

A scanning laser radar (SLR) is required to provide an automatic system for rendezvous and docking of space vehicles. The SLR can provide range, rangerate, angle and angle rate as a navigational aid to a manned rendezvous and docking system. The SLR can also be used for docking with systems that have no retro-reflectors. Further study is required in this area; also further trade studies are required on possible laser sources.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 3

1. TECHNOLOGY REQUIREMENT(TITLE): Scanning Laser Radar PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Utilize non-cooperative rendezvous-to-docking tracking systems (RF system). Utilize TV cameras with star sensors and navigational updates from ground tracking, navigational satellites, or landmark trackers.

The SLR system is the only completely automatic system to satisfy rendezvous and docking.

8. TECHNICAL PROBLEMS:

Evaluation of both CO_2 and GaAs as laser sources and determine the best material that may be applied to a rendezvous and docking scheme.

9. POTENTIAL ALTERNATIVES:

Same as 7.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Applicable to the NASA Space Tug Program.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

None Known.

DEFINITION OF TECHNOLOGY REQUIREMENT

NO. 3

1. TECHNOLOGY REQUIREMENT (TITLE): Scanning Laser Radar

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. CO_2 and GaAs evaluation																			
2. Design System																			
3. Test & Qualification																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE				X														
NUMBER OF LAUNCHES																		

14. REFERENCES:

Contract Nos.. NAS 8-30543- IBM
NAS 8-30738- Norden Division of United Aircraft

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 4

1 TECHNOLOGY REQUIREMENT (TITLE): Development of Low Cost Navigation Components PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Navigation

3. OBJECTIVE/ADVANCEMENT REQUIRED: To reduce the cost of gyros and accelerometers by developing components which have lower inherent cost.

4. CURRENT STATE OF ART: The cheapest inertial quality gyros today cost approximately $7,000; accelerometers cost approximately $1,500-$2,500 each.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Present efforts to develop low cost inertial systems are hampered by the fact that many present day components were developed with performance as the prime goal and cost secondary. In doing this many inherently cheaper concepts have been discarded because they lacked the potential for refinement. There are many applications today which require modest accuracy, but very low cost to make them economically feasible.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6 RATIONALE AND ANALYSIS:

For the last two years (FY 74 & 75) there has been very little R & D support for the development of new inertial components (other than in-house company funds which have mainly aimed at improving older products). There are presently two concepts-one based on a multisensor using tuned rotor technology (Teledyne) and a second concept tracking vibrational modes in a solid, fixed structure which hold much promise and should be funded.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 4

1. TECHNOLOGY REQUIREMENT(TITLE): Development of Low Cost Navigation Components

PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

There are presently at least two potential low cost techniques that show significant promise. Others would probably appear if more funding were available.

8. TECHNICAL PROBLEMS:

This "Definition of Technology Requirements" is for basic development. The technical problems are often unknown; however, both concepts have been carried far enough to know they work. High quality prototype instruments must now be built to evaluate how well they work and their critical features.

9. POTENTIAL ALTERNATIVES:

No change from present programs.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Unless outside funding becomes available the only changes in the state of the art will be minor products improvement. The strapdown systems under development today already have their cost figures built-in.

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 4

PAGE 3 OF 3

1. TECHNOLOGY REQUIREMENT (TITLE): Development of Low Cost Navigation Components

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

1. Spin coupled accelerometer gyro (SCAR) TDN-200 strapdown inertial system; Teledyne systems company report (proprietary) March 1975.

2. The Sonic Gyro; Delco Electronics (proprietary) August 1974.

Observations:

This technology may have more significance to aircraft.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 5

1. TECHNOLOGY REQUIREMENT (TITLE): Autonomous Guidance & Navigation PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Navigation

3. OBJECTIVE/ADVANCEMENT REQUIRED: Enable s/c measurements to be collected and processed with resulting maneuvers and/or science sequence modifications executed.

4. CURRENT STATE OF ART: All measurements are processed on the ground and command decisions are real time or pre-programmed from the ground.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

Development of s/c system that is initiated by ground command or by pre-programming. When activated it will use an optical sensor to detect the position of an extended target body in relation to a star background. These measurements will be processed to determine the orbit and a decision will then be made to execute a trajectory correction maneuver, if required, and/or to adjust or modify a pre-planned target related science sequence.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

This capability allows short reaction-times to be accommodated at large distances from the earth even when the round-trip light time becomes equal to or greater than the available reaction time between latest required observation and latest possible corrective action initiation This capability then allows extreme accuracy required for close approach gravity swingby's to be performed near outer planet satellites and enables a class of missions which could not be done with total earth-based control.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 5

1. TECHNOLOGY REQUIREMENT(TITLE): Autonomous Guidance & Navigation — PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

I. Acquisition and Tracking of a target body.

II. Measurement of target body position relative to star background with orbit determination and trajectory correction maneuver logic. Also capability of adjusting a pre-programmed science sequence if required.

III. In addition to above, also capable of redesigning a pre-programmed science sequence. Also capable of detecting a target of opportunity, e.g., an asteroid, with logic to make decision to change trajectory and devise a science sequence for it.

8. TECHNICAL PROBLEMS:

I. Sensor metric accuracy plus ability to handle wide dynamic range of dim star and bright extended target body.

II. On-board computer capability to handle calculations

III. Softward development to perform tasks: a.) in on board computer environment, b.) in presence of noise, anomolous data, blunder points.

9. POTENTIAL ALTERNATIVES:

Less abmitious missions that do not require the high navigation accuracy.

-longer mission lifetime for same science return.

-less science return for a given mission lifetime.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

JPL Guidance and Navigation for Unmanned Planetary Vehicles (RTOP 506-19-21) is developing plans for a partial flight/ground demonstration and for laboratory demonstrations.

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

Spacecraft computer development.
High metric accuracy sensor with wide dynamic range development.
Orbit estimation software development.
Multiple maneuver strategy development.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 5

1 TECHNOLOGY REQUIREMENT (TITLE): **Autonomous Guidance & Navigation** PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Preliminary Design		—	—																
2. Laboratory Breadboard				—															
3. Laboratory Demonstration					—	—													
4. Flight Demonstration							—	—											
5. Technology Readiness										Δ									
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations												—							
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE										Δ								
NUMBER OF LAUNCHES											1	1	1		1		1	5

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 6

1. TECHNOLOGY REQUIREMENT (TITLE): Differential Very Long Long Baseline Interferometry (VLBI) and Pulsar Navigation PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Navigation

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase the accuracy with which spacecraft can be tracked and located

4. CURRENT STATE OF ART: Accuracy limited by low declination, planetary ephemerides, and large distances from earth

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

I. Differential very long baseline interferometry (VLBI) consists of interferometrically tracking first the s/c and than an extra-galactic source, thus fixing the s/c target relative coordinates to be inertial coordinate system. This allows subsequent flights to be carried out to greater accuracy.

II. Signals from several pulsars are received and recorded at the s/c and also at the earth. Subsequent signal correlation allows spacecraft orbit determination accuracy which does not degrade with increasing distance from the earth.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

I. VLBI Measurements made with s/c is on or near another planet allows that planet's ephemeris to be improved significantly. The differential data technique proves to be sensitive to error sources such as charged particles, non-gravitational forces, low declinations which limit the radiometric tracking accuracy.

II. Several pulsars must be located by the s/c and also by a ground station on the earth. The received signals must be recorded, with accurate timing, and subsequently played back to a common center, where they are correlated. The resulting s/c position determination accuracy will be independent of the s/c earth distance.

III. An alternate technique which would be a next step in the development of autonomous s/c, would be to have a catalog of pulsar characteristics in an on-board memory so that the correlation could be done on the s/c.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 7

1. TECHNOLOGY REQUIREMENT (TITLE): Comet and Asteroid Ephemerides Improvement — PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Navigation

3. OBJECTIVE/ADVANCEMENT REQUIRED: More accurate comet and/or asteroid ephemerides will improve the currently limiting error source for these small-body missions

4. CURRENT STATE OF ART: Astronomical, optical observations are not systematically carried out

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

I. More systematic observation schedule would avoid missing potential observations.

II. Utilization of radar bounce data would add a new dimension to the observations.

III. An autonomous "Search-Satellite" could provide early warning to start observations of new comets or asteroids.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Information relative to the origin of the solar system is expected to be found on comets and asteroids.

Better knowledge of the ephemerides of these small bodies will allow missions to be planned and carried out.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 8

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 2

Cometary Intercept Navigation and Guidance

2. TECHNOLOGY CATEGORY: Navigation

3. OBJECTIVE/ADVANCEMENT REQUIRED: Rendezvous capability with bodies having poorly defined trajectory

4. CURRENT STATE OF ART: Trajectories of bodies must be known with great precision before spacecraft is launched.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Rendezvous with poorly-defined trajectories requires very high energy velocity states with very efficient navigation and the capability for frequent trajectory correction.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Very few comets have trajectories that are known prior to comet detection, and it requires a significant time to establish the trajectory after sighting a comet, often leaving too little time for a spacecraft to rendezvous using conventional techniques of near minimum energy. The availability of a high-energy probe will greatly expand the number and frequency of available comet encounters.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 8

1. TECHNOLOGY REQUIREMENT(TITLE): Cometary Intercept Navigation and Guidance — PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

Restrict the cometary intercept opportunities to those few comets that can be accurately predicted.

8. TECHNICAL PROBLEMS:

1. Obtaining maximum propulsive impulse through use of high specific impulse fuels and solar sailing.

2. Development of optimal navigation strategies and their mechanizations.

9. POTENTIAL ALTERNATIVES:

None.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Electric propulsion and other high-impulse propulsion projects.

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

Comet sensors for rendezvous.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 9

1. TECHNOLOGY REQUIREMENT (TITLE): Automated S/C. PAGE 1 OF 2

2. TECHNOLOGY CATEGORY:

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase capability of spacecraft to perform complex, self-contained tasks.

4. CURRENT STATE OF ART: Present S/C are controlled largely through ground command or pre-stored programs.

HAS BEEN CARRIED TO LEVEL 10

5. DESCRIPTION OF TECHNOLOGY

Development of spacecraft which will be able to interact with the environment and perform tasks involving qualitative decisions. Included are such tasks as orbit changes, instrument pointing and control, autonomous manipulation and roving vehicle control. Areas of development include the structure of the control elements, the process of decision making (problem solving), interaction between the spacecraft and the human controller, techniques for computer controlled manipulation and roving vehicle control.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Two basic physical limitations force the development of autonomous S/C. First there is the time delay between S/C and earth at large interplanetary distances. Second is the bandwidth needed to supply the information human operators need to maintain detailed control of the task. To overcome these two problems, spacecraft should have the ability to perform complex detailed tasks, leaving the human operator to exercise supervisory control. As mission requirements become more complex, spacecraft will either become more complex, or several spacecraft will be flown, each doing part of the mission. Either case will be costly in terms of dollars and reliability, requiring alternative methods of S/C control.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 9

1. TECHNOLOGY REQUIREMENT(TITLE): Autonomous S/C PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

1. Artificial Intelligence, which means that the spacecraft can supervise itself and has built-in goals. The human operator only receives data.

2. Supervisory control, wherein the human operator sets short term goals (still at a high level) and monitors the performance of the S/C. The intelligence is limited and may be in either sensors or computers.

3. Teloperators, wherein the human operator directs actual motion of the S/C.

8. TECHNICAL PROBLEMS:

1. Computing capability. This should be resolved by future computer developments.
2. Software generation. Application of structured programming is required.
3. Vision requires sensing and interpreting environmental data for a world model.
4. Control structure--the hierarchy of control elements.
5. Vehicle control-roving vehicle guidance on journies of 100's of km.

9. POTENTIAL ALTERNATIVES:

Alternative methods of performing bandwidth limited or long range missions are:

1. Manned S/C.
2. Limited purpose S/C, with several types of S/C used for each mission.
3. Complex S/C pre-programmed for every foreseen option.
4. Automated S/C.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

JPL Robot Research Program involved in producing an integrated, automated vehicle. Low level development program aimed at producing technology in the mid 1980's.

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

1. Computer architecture.
2. Vision sensors.
3. Information processing:
4. Manipulator design.
5. Man-machine relationships (Graphics, etc.)

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 10

1. TECHNOLOGY REQUIREMENT (TITLE): Robotic Decision Making and Planning PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Automated Spacecraft

3. OBJECTIVE/ADVANCEMENT REQUIRED: Ability to plan and implement a task or series of tasks once a high level supervisory command statement has been sent to the robot.

4. CURRENT STATE OF ART: Only simple, limited task planning and execution is possible with today's technology.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Even a primitive robot must have certain capabilities related to decision making and planning. The fact that a robot can complete a task automatically implies that it has some internal representation of a goal, perhaps expressed as a state of the machine and of its environment, and that it possesses some built-in criteria for deciding that the goal has been reached. Then, given an initial state and desired final state, the robot must be able to make a plan--that is, a sequence of action of sensors and effectors that will achieve the final state.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

Decision making and planning are functions that human beings perform rather effortlessly and well. Very little is known about how to automate them. An implicit assumption in most current teleoperator work is that human beings will make the decisions and plans that affect what the remote system does and how it does it. This assumption will at first also be valid for robots for all but a few sensor and motor functions, but there is motivation eventually to delegate some additional decision-making and planning responsibilities to the remote machine to make it more independent of earth-based surveillance. If such a degree of autonomy could be achieved, it would benefit some earth and near-earth applications as well.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 11

1. TECHNOLOGY REQUIREMENT (TITLE): Robotic Scene Analysis — PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Automated Spacecraft

3. OBJECTIVE/ADVANCEMENT REQUIRED: Automatic analysis of sensor data (usually pictures) to allow the robot to develop a model of the surrounding environment.

4. CURRENT STATE OF ART: Automatic analysis of well defined objects on a contrasting, uncluttered, background is possible.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

For a robot to operate autonomously it must develop a model of its surroundings. This model, located in the robot's computer, will allow save movement from place to place and permit the carrying out of commanded functions (pick up rock located at a specific location, etc.). Scene analysis, which is closely related to the function of perception, involves computer dissection of pictures, combination of this data with other sensory data from instruments such as laser range finders and construction of a "world model". This model is continually updated and corrected as the robot moves in carrying out its tasks.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

In robotics, a central long-range objective is to automate as much of the function of perception as is possible. If this sensorimotor control control loop can be closed locally, through the machine rather than through the human operator, the amount of sensory data (largely pictures) that must be transmitted back to the human supervisor can be greatly reduced, and the downlink communication channel used more effectively for other control and scientific purposes.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 11

1. TECHNOLOGY REQUIREMENT(TITLE): Robotic Scene Analysis PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

The data provided to the robot for scene analysis can come from a variety of sensors whose data can be combined and weighed in various ways. Stereo-pictures, mono-pictures, laser range data taken at different locations can all be used to construct an optimum "world model"

8. TECHNICAL PROBLEMS:

The analytical models required to dissect the input data in real time or near real time are extremely complex and poorly developed. The development of models that are not only correct and provide a useful world model but will operate with the robots available computer size is a major problem.

9. POTENTIAL ALTERNATIVES:

Continue to operate in the less efficient teleoperator mode where picture analysis and the integration of other sensor data is done by the human operator.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-19-31 Artificial Intelligence
RTOP 506-19-32 Artificial intelligence for Integrated Robot Systems

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

Artifical intelligence, vision, perception, T.V. scene analysis

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 12

1. TECHNOLOGY REQUIREMENT (TITLE): End Effector Sensors For Robot And Teleoperator Manipulators — PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Automated Spacecraft and Teleoperators

3. OBJECTIVE/ADVANCEMENT REQUIRED: To develop end effector sensors that give a "sense of presence" to the human operator or the robot computer to more easily carry out the required task

4. CURRENT STATE OF ART: Limited touch, force and proximity sensors are now available. Their effective integration into the systems has not been achieved.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Various types of sensors can be used on end effectors of remote manipulation process. Touch sensors, force feedback sensors, optical proximity sensors and variou pressure sensors can all be used for this purpose. The presentation format of this data to the teleoperator operator or to the robot computer and how this data should be interpreted and used by the operator and computer are major technology problems.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Without these end effector sensors it is often difficult or impossible to determine the location of the effector with respect to the object being grasped. Contact with the object of interest may be too hard--damaging it--or too light causing it to be dropped. In any event, making proper contact without these sensors will greatly increase the time required to perform a given task.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 14

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 3

STELLAR II (Star Tracker)

2. TECHNOLOGY CATEGORY: Spacecraft Attitude Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Radiation hardening and increased reliability and lifetime of spacecraft attitude control star tracker.

4. CURRENT STATE OF ART: STELLAR, utilizing solid state CCD image sensor and microprocessor for signal processing.

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

STELLAR II is an internally redundant, radiation hardened and fault tolerant CCD star tracker; a direct outgrowth of the STELLAR star tracker now under development. STELLAR incorporates several hundred integrated circuits, microprocessor and a CCD. In numerous cases single point component failures could generate catestrophic tracker failures.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

STELLAR II will achieve a major increase in reliability and lifetime, consistent with the full-time operation, mission-critical role of the star tracker through radiation hardening and fault tolerance. Radiation hard components will be selected and shielding included as necessary. The CCD imager will be capable of bi-directional readout, thus bypassing a failed readout register or on-chip amplifier, and the signal processing elements will be redundant, capable of self test, and reconfigurable to bypass failed logic or memory elements. All operating parts will be integrated circuits stressed to a low level.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 14

1. TECHNOLOGY REQUIREMENT(TITLE): STELLAR II PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

An alternative option is to use two block redundant STELLAR units, and a switching circuit. The second unit would not be turned-on unless the first had failed.

8. TECHNICAL PROBLEMS:

Little is known at this time about radiation hardness of CCD's. Shielding may be necessary.

9. POTENTIAL ALTERNATIVES:

Block redundant sensors.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

VIP - STELLAR, star mapper and tracker intended for SIRTF, also planetary mission STELLAR

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

Self test and reconfiguring software.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 14

1. TECHNOLOGY REQUIREMENT (TITLE): STELLAR II — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Functional Require.		—	Δ																
2. B.B. Design & Fab.			—	Δ															
3. Programming				—	Δ														
4. Test & Development					—	Δ													
5.																			
APPLICATION																			
1. Design (Ph. C)						—Δ													
2. Devl/Fab (Ph. D)							—	—	Δ										
3. Operations									—	—	—	—	—	—	—	—	—	—	—
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE						Δ											TOTAL
NUMBER OF LAUNCHES																	

14. REFERENCES:

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND [illegible]
2. [illegible] PHENOMENA
3. [illegible]
4. [illegible] DEMONSTRATED, [illegible]
5. COMPONENT OR BREADBOARD [illegible] ENVIRONMENT [illegible] LABORATORY
6. MODEL TESTED IN AIR [illegible]
7. MODEL TESTED [illegible]
8. NEW CAPABILITY [illegible] OPERATIONAL MODEL
9. RELIABILITY [illegible]
10. LIFETIME [illegible]

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 15

1. TECHNOLOGY REQUIREMENT (TITLE): — PAGE 1 OF 3

Intensified Solid State Imaging Device

2. TECHNOLOGY CATEGORY: Imaging

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop a low light level, solid state imaging device by integrating a "CID" imaging device with an imaging intensifier.

4. CURRENT STATE OF ART: CID devices have been built but have not been integrated with image intensifiers

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

A technique for increasing the sensitivity of "Charge Injected Devices" (CID) imaging devices in order to more completely take advantage of their ruggedness, size, weight, and low power consumption. These devices will be strong competitors to present low light level, tube type systems.

P L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

(a) As the resolution of solid state devices increase, devices such as the CID will begin to replace tube type imaging devices. As the sensitivity of CID type devices is increased, by integration with intensifiers, intensified CID's could replace all tube devices.

(b) The great advantages of the solid state imaging devices are:

1. Elimination of a heater element.
2. Very small size, compared to an equivalent tube device.
3. Light weight.
4. Ruggedness, due to the elimination of electrodes.
5. Elimination of magnetic fields.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 15

1 TECHNOLOGY REQUIREMENT(TITLE): Intensified Solid State Imaging Device PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

(a) Continued development and improvement in tube type imaging devices.

8. TECHNICAL PROBLEMS:

(a) Contamination of the CID silicon chip by materials from the intensifier photocathode.

(b) Damage to the CID by high energy particles within the system.

9. POTENTIAL ALTERNATIVES:

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 15

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 3 OF 3

Intensified Solid State Imaging Device

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis & Design																			
2. Fabricate Test Model																			
3. Test																			
4. Evaluation																			
5. Report: Results																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

Observations:

1. Sent to Sensors Group for Consideration.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 16

1. TECHNOLOGY REQUIREMENT (TITLE): Charge Injection Devices for Low Light Level Imaging PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Imaging

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop high performance, long life detectors for low light level sensors to supersede the conventional, high voltage photocathode tube.

4. CURRENT STATE OF ART: Small arrays in commercial TV cameras.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

(a) Fabricate a Charge Injection Device (CID) for use as an optical sensor in a solid state star tracker. Modifications of existing commercial CID's will improve resolution, sensitivity, and uniformity through sizing and selection.

(b) Design tracker electronics to minimize the power, weight and size requirements and to take advantage of the capabilities unique to solid state array sensors.

(c) The options of nondestructive readout and random access of photoelements should be exploited for applications requiring image storage or high bandwidth tracking response.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

A star tracker using a solid state array sensor has the following advantages over a conventional image dissector tracker.

(a) No high voltage requirement with its associated problems in space vacuum.
(b) Not sensitive to ambient magnetic fields.
(c) Sensor is light-weight, compact, and a low power dissipator. Its spatial array is metrically stable, not requiring precise magnetic deflection circuitry for position calibration.
(d) Wide range spectral responsivity (8000 Å to 4000 Å) and high (70%) quantum efficiency.

The CID sensor has the following advantages over Charge Coupled Devices (CCD).

(a) High percentage of array area is photo sensitive; no interlaced transfer registers.
(b) Low thermal (dark) current generation inherent to device physics.
(c) Good UV sensitivity without substrate thinning.
(d) Can be randomly accessed as opposed to sequentially scanned.
(e) May be nondestructively readout.

The low power, small size, long life and operational versatility enhance the CID tracker's potential as a widely used, off-the-shelf component.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 16

1. TECHNOLOGY REQUIREMENT(TITLE): PAGE 2 OF 3

Charged Injection Devices for Low Light Level Imaging

7. TECHNOLOGY OPTIONS:

(a) Adapt commerically available (TV compatible) solid state sensors and/or electronics to star tracker requirements.

(b) Accept the limitations of commercial sensors and attempt to develop sophisticated video data handling techniques to improve system performance.

(c) Accept charge coupled devices (CCD) for solid state sensors.

(d) Continue to use image dissector tubes.

8. TECHNICAL PROBLEMS:

(a) All solid state sensors will require cooling (-40 C to -70 C) to achieve sensitivity and dynamic range goals for star tracker performance. Preliminary studies show that passive cooling will suffice, but allowance must be made for stable temperature control.

(b) State-of-the-art in solid state sensors is young, and the full potential has not been developed. The quality/cost ratio should increase rapidly, just as in other areas of semi-conductor development.

9. POTENTIAL ALTERNATIVES:

Continue to develop tube-type star tracker systems to meet a wide range of applications, and to limit the scope of operational functions that can be practically achieved.

10 PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Industrial/commercial development will continue at a high level.

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

Optical imaging
- (a) Commercial TV requirements for high and low light level applications
- (b) Ground and space-borne astrophysical experiments

Non-Optical applications
- (a) Computer memory
- (b) Telemetry buffers
- (c) Delay lines

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 16

11. TECHNOLOGY REQUIREMENT (TITLE): Charged Injection Devices for Low Light Level Imaging   PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Develop Requirements	—																		
2. Study & Analysis		—																	
3. Tracker breadboard		—	—																
4. Test and Evaluate			—																
5. Tracker packaging				—															
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE						X												
NUMBER OF LAUNCHES																		

14. REFERENCES:

GE Memo, "CID (Charge Injection Device) Theory of Operation," June 1975.

CCD Symposium paper, "Planetary Investigation Utilizing an Imaging Spectrometer System Based upon Charge Injection Technology," R. B. Wattson, P. Harvey, and R. Swift.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 17

1. TECHNOLOGY REQUIREMENT (TITLE): Optical Standardization and Improved Tube Design for Star Trackers PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Imaging

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improve photocathode tube performance in accuracy, linearity & resolution. Required to satisfy requirements of future space missions.

4. CURRENT STATE OF ART: Utilize the standard ITT F 4012 RP image dissector tube and provide excessive calibration procedures.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

(a) Perform modifications and design changes to the basic F4012RI image dissector tube. Reposition the internal parts, increase tube length, modify mounting and improve potting materials.

(b) Design and develop an optical lens system compatible with the F 4012 RP image dissector tube. Incorporate the design in a star tracker and evaluate.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

(a) Technical advancements have been made under previous in-house work at MSFC and a contract with ITT. The results indicate that the linearity can be greatly improved with relatively simple modifications to the tube's internal parts.

(b) The existing in-house star tracker designs utilize a very poor quality, simple photographic lens. These optics are inadequate to achieve high performance pointing data and star mapping.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 17

1. TECHNOLOGY REQUIREMENT(TITLE): Optical Standardization and Improved Tube Design for Star Trackers

7. TECHNOLOGY OPTIONS:

(a) Consider a second source for photocathode tubes for star tracker application.

(b) Improve higher quality standards on the contractor.

(c) Rely on the next generation of star trackers utilizing solid state detectors.

8. TECHNICAL PROBLEMS:

(a) Designing a lens system to suit the F 4012 RP tube.

(b) Designing the internal parts and establishing the critical spacing of components.

9. POTENTIAL ALTERNATIVES:

Continue to provide lengthy calibration procedures and accept low quality.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

(a) Fine guidance sensor under development for LST.

(b) Solid state star tracker development.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 17

1. TECHNOLOGY REQUIREMENT (TITLE): Optical Standardization and Improved Tube Design for Star Trackers — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Develop Requirements																			
2. Contract																			
3. Test & Evaluate																			
4. Integrate into Star Tracker																			
5.																			
APPLICATION *																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE			X															
NUMBER OF LAUNCHES																		

14. REFERENCES:

Final report on Contract NAS8-29918.

*Applicable to existing state-of-the-art designs with near term users.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 18

1. TECHNOLOGY REQUIREMENT (TITLE): STRAY-LIGHT REJECTION PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Navigation, Guidance and Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop a methodology for assessing the performance of stray-light shields to improve rejection of sunlight, albedo, and spacecraft reflections

4. CURRENT STATE OF ART: Designs and analyses have been done on stray-light shields for specific applications

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

a) Establish a methodology for predicting the performance and attenuation capabilities of stray-light baffle configurations as a function of geometry, materials, and source characteristics.

b) Develop a computer program which provides synthesis and analysis of various configurations for optimization studies.

c) Test some representative designs in space environment (Shuttle Sorties) for comparison with analytical data.

d) Refine theory to agree with practice.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) Performance of star-trackers, star-mappers, horizon sensors, etc., is affected by stray light radiation entering the instrument field-of-view.

b) All payloads using stellar-reference sensors require stray-light rejection and would benefit from this technology.

c) Most methods for designing and testing stray-light rejection hardware require crude ray tracing requiring development of special techniques for each configuration.

d) This technology advancement should be carried to an experimental demonstration on a shuttle flight to verify predicted performance.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 18

1. TECHNOLOGY REQUIREMENT(TITLE): Stray-light Rejection PAGE 2 OF 4

7. TECHNOLOGY OPTIONS:

The alternatives to the proposed technology are to continue evaluating each stray-light shield as a separate entity requiring unique analysis or to construct special facilities for testing the various configurations. Both methods require considerable expense of funds and time.

8. TECHNICAL PROBLEMS:

The biggest technical problem lies in development of the analytics describing the behavior of radiation within a configuration. The mathematics are very complex for describing radiative transport (specular, diffuse, specular-diffuse, diffraction) within a shield.

9. POTENTIAL ALTERNATIVES:

Construction of special test facility and continued cut-and-try (ray-tracing) approach.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

The STS Advanced Systems Technology Guidance and Control Working Group defined an FY 75 New Start with the goal of constructing a special facility for agency-wide use for testing sunshades.

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 18

1 TECHNOLOGY REQUIREMENT (TITLE): Stray-Light Rejection PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analytical model and computer program develop.																			
2. Design and fabrication of representative shields																			
3. Lab test of shields																			
4. Comparison of data and model refinements																			
5. Space checkout of shields and data comparison																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE	Δ																	
NUMBER OF LAUNCHES						1		1										2

14 REFERENCES:

1. Jackson, D. B., SPARS Phase IB Sunshield Development Program Final Report, TM-21290-52, Honeywell Inc., Minneapolis, Minnesota, 23 October, 1970.

2. Walsh, Thomas M. and Hinton, Dwayne E.: Development and Application of a Star-Mapping Technique to the Attitude Determination of the Spin-Stabilized Project Scanner Spacecraft. Proceedings of the Symposium on Space-craft Attitude Determination September 30, October 1-2, 1969.

3. Heinisch, R. P. and Chou, T. S.: Numerical Experiments in Modeling Diffraction Phenomena. Applied Optics, Vol. 10, No. 10, October, 1971.

4. Sparrow, E. M., Gregg, J. L., Seel, J. V. and Manon, P., "Analysis, Results and Interpretation for Radiation Between Some Simply Arranged Gray Surfaces," Trans. ASME, J. Heat Transfer, 83C, 307, 1961.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 18

1. TECHNOLOGY REQUIREMENT (TITLE): Stray-Light Rejection PAGE 4 OF 4

5. Eckert, E. R. G. and Sparrow, E. M., "Radiative Heat Exchange Between Surfaces With Specular Reflection," Int. J. Heat Mass Transfer, 3, 42, 1961.

6. Lim, S. H. and Sparrow, E. M., "Radiant Interchange Among Curved Specularly Reflecting Surfaces: Application to Cylindrical and Conical Cavities," Trans. ASME, J. Heat Transfer, 87C, 298, 1965.

7. Seban, R. A., "Discussion of Sparrow, et al," In Trans, ASME, J. Heat Transfer, 84C, p. 294, 1962.

8. STS Advanced Systems Technology Guidance and Control Working Group, R. G. Chilton, Chairman, Johnson Space Center, January 1974.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 19

1. TECHNOLOGY REQUIREMENT (TITLE): High Resolution, Long Life Inertial Reference Unit PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Inertial reference units

3. OBJECTIVE/ADVANCEMENT REQUIRED: Fine pointing capability of spacecraft of 1 arc second or less for periods up to 1 hour and life of 10 years is required.

4. CURRENT STATE OF ART: DRIRU fine pointing capability is not determined, and reliability is compromised by ball bearings. Conventional gyros are more expensive.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Both the fine-pointing requirement and the long-life requirement can be satisfied by upgrading the present design of the Dry Gyro Inertial Reference Unit (DRIRU). The fine pointing capability requires the development of higher resolution torquer electronics. The long-life requirement requires improved rotor bearings. For example, a fluid bearing gyro now in an early development stage could eventually be substituted for the present ball bearing gyro. Other gyro designs could also be considered. The incorporation of a fluid bearing also enhances the fine pointing capability of the higher resolution DRIRU in that the noise content of the gyro output is significantly reduced.

P L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The dual requirements of long gyro life and fine pointing are not achievable with the presently used IRU's equipped with ball bearing gyro.

Observations: Include gyro designs other than fluid bearings.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 19

1 TECHNOLOGY REQUIREMENT(TITLE): High Resolution, Long Life Inertial Reference Unit PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

None.

8. TECHNICAL PROBLEMS:

Electronic Torquer development.

Fluid bearing development.

9. POTENTIAL ALTERNATIVES:

IRU's based on single-axis gas bearing gyros.

10 PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Fluid bearings will be brought to feasibility demonstration.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 20

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 3

Cryogenic Gyroscopes for Space and Aircraft Navigation

2. TECHNOLOGY CATEGORY: Attitude Reference

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop Cryogenic Gyroscope Systems for Precision Low Gravity Attitude Reference (unidirectional year); and for Considerably Improved One-G Drift Performance.

4. CURRENT STATE OF ART: Cryogenic Gyroscope being Developed for OSS Gyro-relativity Experiment; Actual Drifts Not Yet measured, but First Flight (Shuttle, 1980?) calls for 0.1 arc-sec year and should be attainable.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

The Gyro being developed consists of a 39 MM quartz shpere rotor with a superconducting niobium coating spinning at 200 hz. The rotor is electrostatically suspended in a quartz housing. Symmetry, weak suspension forces, careful magnetic shielding, and the use of a superconducting electronic readout which senses the very weak magnetic field generated by the spinning superconducting coating, will permit reduction of residual drifts by five orders of magnitude or more from 1-G values. Careful analysis indicated that residual drifts approaching 1 milli-ARC SEC per year should be possible for unidirectional pointing. Readout system limitations will reduce omnidirectional readout precision to 1 arc sec per year.

P L REQUIREMENTS BASED ON: ☐ PRE-A, ☒ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

The Cryogenic Gyro is being developed solely as a scientific instrument to measure precisely two general relativisitic effects (approximately 7 arc-sec per year and 0.05 arc-sec per year respectively). Its application to high accuracy space navigation such as advanced LST's etc., seems obvious and the capability of such a system in a one-G systems should also be investigated.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 20

1 TECHNOLOGY REQUIREMENT(TITLE): Cryogenic Gyroscopes for Space and Aircraft Navigation — PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Conventional gyro systems are, of course, presently available. However, the cryogenic gyro should furnish significant advantages. An alternative precision gyroscope involving a rotating container of superfluid helium at temperatures below 20K has been suggested. Ultimate accuracy could approach that of the quartz-superconductor gyro, but development problems appear very difficult.

8. TECHNICAL PROBLEMS:

No problems have arisen in the development program at Stanford Univ. or at MSFC, or in the theoretical analyses to indicate that ultimate accuracies of at least a few milliarc seconds per year cannot be achieved. A critical subsystem, being actively pursued, is the superconducting readout system.

9. POTENTIAL ALTERNATIVES:

See 7.

10 PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

The Gyro is tentatively identified for an initial, low accuracy flight on an early shuttle (Late 1980?) and for a final, high accuracy flight about two years later.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

a. Superconducting instrumentation for the gyro readout subsystem and, if available, for other electronic systems in the spacecraft.

b. Liquid Helium Dewars suitable for long duration space operation.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 20

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 3 OF 3

Cryogenic Gyroscopes for Space and Aircraft Navigation

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES																		

14. REFERENCES:

1. Decher, R., "Gyroscope Relativity Experiment" NASA TMX-64630, Oct. 18, 1971

2. Hendricks, J., "A Squid Readout System [illegible] Superconducting Gyroscope" IEEE Transactions on Magnetics, VOL MAG-11, Mar 75, Pg. 782

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 21

1. TECHNOLOGY REQUIREMENT (TITLE): Continued Development of Digital Rebalance Electronics for Dry Tuned Rotor Gyros PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: ____

3. OBJECTIVE/ADVANCEMENT REQUIRED: New Digital Rebalance Loops for Two-Axis Dry Tuned Rotor Gyros having improved resolution and accuracy.

4. CURRENT STATE OF ART: (1.) Analog Rebalance Loops (2) Breadboard Digital Rebalance Loop for Kearfott Gyroflex (U.T.K.)

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

A rebalance electronic package consisting of a digital control and data generation section, an error-signal-processor for each of the two axes, a precision, stable torque current pulse generator for each axis, and appropriate power supplies.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

The new digital rebalance loops offer the following advantages over available rebalance loops:

(1.) High accuracy due to use of state-of-the-art electronic devices and low noise circuit design techniques, along with the inclusion of the analog-to-digital conversion process inside a high gain electronic loop.

(2.) High resolution due to fine quantization of the torque-current pulse; e.g., present breadboard resolution is within .024 arc-sec for 2°/sec torquing.

(3.) Since the data corresponding to inertial sensor motion is in digital format, it can be easily processed by computers.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 21

1. TECHNOLOGY REQUIREMENT(TITLE): Continued Development of Digital Rebalance Electronics for Dry Tuned Rotor Gyros

7. TECHNOLOGY OPTIONS:

a. Analog control loops.

b. Analog loops with A/D converters.

8. TECHNICAL PROBLEMS:

(1) Gyro models are inadequate.
(2) Correlated transient feed-through within gyro.
(3) Torquer resistance of gyros too high for optimum design of rebalance loop.

9. POTENTIAL ALTERNATIVES:

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

a. Digital pulse rebalance loops for redundant laser IMU.
b. To extend development for dry tuned rotor gyros with higher rates (30°/sec) with two or three scale-factor switches in the design.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

Development of a dry tuned rotor gyro specifically designed for pulse rebalance techniques (low torquer resistance and low feed-through from gyro torquer to gyro pickoff).

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 21

11. TECHNOLOGY REQUIREMENT (TITLE): Continued Development of Digital Rebalance Electronics for Dry Tuned Rotor Gyros — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Complete work on gyroflex gyro	Δ																		
2. Studies on cross-coupling effects	—																		
3. Design PR electronics for high rate gyro		—																	
4. Perform dynamics test for axes interaction			—																
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE																	
NUMBER OF LAUNCHES																	

14. REFERENCES:

1972 - 73 ------ U. T. Annual Report

1973 - 74 ------ U. T. Annual Report

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 22

1. TECHNOLOGY REQUIREMENT (TITLE): High Resolution Attitude Sensor PAGE 1 OF 3

2. TECHNOLOGY CATEGORY:

3. OBJECTIVE/ADVANCEMENT REQUIRED: To develop and test a high resolution attitude sensor for space missions and experiments.

4. CURRENT STATE OF ART: Current attitude sensors can be expected to perform no better than 0.01 arc-second for short periods of time.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

This sensor would be a laser gyro utilizing and expanding the technology "spin-offs" from the development of the strapdown laser IMU.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The high resolution attitude sensor is needed for the Large Space Telescope (LST) and other experiments. Some of these requirements are 0.001 arc-second accuracy for relatively long periods of time of attitude control.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 22

1. TECHNOLOGY REQUIREMENT(TITLE): High Resolution Attitude Sensor PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

1. Laser gyro increase in stability and resolution.
2. Laser interferometer with fiber optics.
3. Special technology development in new approaches.

8. TECHNICAL PROBLEMS:

High resolution sensors require extremely tight controls on temperature, dimensional stability, voltage and test procedures.

9. POTENTIAL ALTERNATIVES:

There are several approaches being proposed by different sources that could solve some of the problems associated with a greater resolution and accuracy of inertial sensors; some of these are listed in Item 7.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

There are plans to investigate the different proposed methods of producing a high resolution inertial sensor in FY 76.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 22

1. TECHNOLOGY REQUIREMENT (TITLE): High Resolution Attitude Sensor — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Develop Requirements	—																		
2. Contract		—	—																
3. Test & evaluate				—															
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE					X													
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 23

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 3

Low-g Accelerometer Evaluation Facility

2. TECHNOLOGY CATEGORY: Accelerometers

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide a facility for testing accelerometers with an uncertainty of 10^{-8} m/s^2

4. CURRENT STATE OF ART: 10^{-5} m/s^2

HAS BEEN CARRIED TO LEVEL NA

5. DESCRIPTION OF TECHNOLOGY

A space facility avoids the 1-g field of earth facilities. The space facility must provide precise accelerations for calibration of the accelerometer as well as support functions like power, data processing, alignments, etc.

P L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

The one-g earth gravity and the difficulty of isolating seismic disturbances restrict the limit of accelerometer testing to about 10^{-5} m/s^2.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 23

1. TECHNOLOGY REQUIREMENT(TITLE): Low-g Accelerometer Evaluation Facility — PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

In lieu of a shuttle-borne test facility, fly accelerometers as technological experiments on suitable earth-orbit missions. This is quite expensive and is suitable only for design proof testing unless spacecraft is recoverable.

8. TECHNICAL PROBLEMS:

Design of test facility instrumentation

9. POTENTIAL ALTERNATIVES:

Use earth laboratory facilities and employ extrapolation and analysis to estimate the space performance.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None known

EXPECTED UNPERTURBED LEVEL 0

11. RELATED TECHNOLOGY REQUIREMENTS:

Earth atmosphere drag experiments (DOD)

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 23

1. TECHNOLOGY REQUIREMENT (TITLE): Low-g Accelerometer Evaluation Facility — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. **Feasibility Study**																			
2. **Design Definition**																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4. **Initial Flight**					Δ														

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE											Δ							
NUMBER OF LAUNCHES						1					1	1	1	1	1	1		7

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 24

1. TECHNOLOGY REQUIREMENT (TITLE): Rate Gyro Package — PAGE 1 OF 1

2. TECHNOLOGY CATEGORY:

3. OBJECTIVE/ADVANCEMENT REQUIRED: To flight qualify a rate gyro package for long space missions and aircraft applications with high reliability and low cost.

4. CURRENT STATE OF ART: A laser gyro rate package is being developed for an operational demonstration test.

HAS BEEN CARRIED TO LEVEL _

5. DESCRIPTION OF TECHNOLOGY

The laser gyro rate package is an inertial sensor package rigidly mounted to the vehicle frame to measure angular rates for attitude control and stabilization of the vehicle. The laser gyro rate package will take advantage of the laser gyro characteristics (low power, long life, wide dynamic range, no moving parts, insensitive to gravity, less error in a dynamic environment, less navigation computations).

P. I. REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The sel[illegible] laser gyro rate package is ideally suited for strapdown applications and strapdown systems are ideally suited for redundancy management for high reliability. The laser gyro rate package will provide the required high reliability and low cost sensors for future space and aircraft applications.

TO BE CARRIED TO LEVEL _

1. TECHNOLOGY REQUIREMENT(TITLE): Rate Gyro Package

7. TECHNOLOGY OPTIONS:

The wide dynamic range of the laser gyro rate package could make it a standard rate package for many different applications.

The present uses of rate gyro packages have to be designed for each application depending on the range of rates of operation, reliability required, signal outputs, power, etc.

The NASA standard DRIURU would be an option for consideration.

8. TECHNICAL PROBLEMS:

The bending modes of certain vehicles require that several sets of rate gyro packages have to be placed in various places throughout the vehicle. With the present sensor packages this is a costly, complex problem with all vehicles as proven with the Skylab rate gyro failure problems.

9. POTENTIAL ALTERNATIVES:

To flight qualify the laser gyro rate package. Several types of laser gyros have been tested in flight to prove operational capability in a dynamic environment.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

The laser gyro rate package is planned for development in FY76 and will be self-contained with the desirable characteristics of the laser gyro and its wide dynamic range. This rate package could become the standard package for many applications of rate sensor packages.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

Low cost, highly reliable, low power gyros for aircraft navigation systems, space rate gyro packages and high resolution sensors for special pointing applications.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 24

1. TECHNOLOGY REQUIREMENT (TITLE): Rate Gyro Package PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. SR&T Laser Rate Gyro Development	—	—																	
2. SR&T Package Integration		—	—																
3. SR&T Rate Gyro Package Test			—	—															
4. Space Tug Avionics Build				—	—	—	—	—	—										
5. First Space Tug Flight									—	—	—	—	—	—	—	—	—	—	—
APPLICATION																			
1. Design (Ph. C)				—	—	—	—												
2. Devl/Fab (Ph. D)						—	—	—	—										
3. Operations									—	—	—	—	—	—	—	—	—	—	—
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES									6	12	12	12	12	12	12	12	12	102

14. REFERENCES:

1. "Space Tug Avionics Definition Study: by General Dynamics".
2. "Space Tug Definition Documents".
3. "Space Tug Baseline Requirements Definition Documents" by MSFC.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 24

1. TECHNOLOGY REQUIREMENT (TITLE): Rate Gyro Package PAGE 4 OF 4

The Avionics System for the full-capability Space Tug to be developed by NASA for initial operations in late 1983 will be driven by requirements of (1) performance to deliver 8000 pounds of payload into geosynchrononous orbit and retrieve 3500 pounds, (2) mission duration up to 185 hours, (3) payload retrieval with potential for on-orbit servicing in the future, (4) autonomous flight operations, (5) Shuttle crew safety and mission success reliability (0.97 for all missions), and (6) 1983 IOC date for first operational flight. The 1978 Phase C/D timing will allow the Tug program to take maximum advantage of technology advances in the avionics implementation of these requirements to attain low system weight, power system capacity, sensors and softward for rendezvous and docking, navigation update, checkout, redundancy and its management.

The advanced technology nature of this avionics system has a significant influence on the system's total development cost. The advanced components selected for the baseline system definition were projections from research/technologies presently being pursued. From the current status of these technologies, the further technology development effort was defined that would be required before component design and development could be started or procurement specifications prepared. This is an essential first step in the whole process of getting an advanced hardware system designed, built, tested, qualified, and flown. There are two approaches for the accomplishment of these needed additional technology activities:

a. Perform these activities after Phase C/D starts. The overall Tug development schedule calls for Phase C/D to start late 1978, culminating with first operational flight in December 1983. The total DDT&E cost of avionics development for this approach was estimated to be $92.8 million.

b. Perform these activities during the three-year period prior to the start of Phase C/D. The confidence gained by the early solution to problems and the proofing of techniques will reduce the risk during the actual component development phase and will reduce the total DDT&E cost of avionics development to $74.1 million.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 25

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 4

Redundant Strapdown Laser Inertial Measurement Unit (IMU) for Space Missions

2. TECHNOLOGY CATEGORY:

3. OBJECTIVE/ADVANCEMENT REQUIRED: To flight qualify a redundant strapdown IMU for long space missions and aircraft applications with high reliability and low cost.

4. CURRENT STATE OF ART: A laser gyro redundant strapdown IMU is being constructed for operational demonstration test.

HAS BEEN CARRIED TO LEVEL

5. DESCRIPTION OF TECHNOLOGY

The redundant strapdown laser gyro IMU navigation system is an inertial system with sensors mounted rigidly to the vehicle frame in a dodecahedron configuration. This is the configuration that gives the most effective redundant management. The IMU will take advantage of all the characteristics of the laser gyro (low power, long life, wide dynamic range, no moving parts, insensitive to gravity, less errors in a dynamic environment, less navigation computations).

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The laser gyro is ideally suited for strapdown applications and strapdown dystems are ideally suited for redundancy management for high reliability. The laser gyro redundant strapdown IMU will provide the requirements of high reliability and low cost for future space aircraft applications.

TO BE CARRIED TO LEVEL

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 25

1. TECHNOLOGY REQUIREMENT(TITLE): Redundant Strapdown Laser Inertial Measurement Unit (IMU) for Space Missions — PAGE 2 OF 4

7. TECHNOLOGY OPTIONS:

The system of present technology for Space Shuttle is three, three axis conventional IMU's operating in parallel. Each weighs 75 pounds and requires 354 watts of power to operate, including the control electronics.

8. TECHNICAL PROBLEMS:

The current gyro is designed for aircraft operation with fan blowers and limited freedom in some gimbal axis. For space applications the thermal controls and gimbals will have to be redesigned. These changes will have to be made in addition to the disadvantages of high weight and power.

9. POTENTIAL ALTERNATIVES:

To flight qualify the laser gyro redundant strapdown IMU, several different three axis laser gyro IMU's have been laboratory tested, mobile van tested and flight tested to prove capability of navigation in a dynamic environment.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

The laser gyro redundant strapdown IMU is presently under construction. This IMU will be mated with a computer and software programs for calibration, alignment, navigation and redundancy management. This system will be tested in the laboratory, mobile van, and aircraft for operational evaluation.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

Low cost, redundant, highly reliable, low power IMU's for aircraft navigation systems, space rate gyro packages, and high resolution sensors for special pointing applications.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 25

11. TECHNOLOGY REQUIREMENT (TITLE): REDUNDANT STRAPDOWN IMU FOR SPACE MISSIONS — PAGE 3 OF 4

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. SR&T Redundant Strapdown laser IMU build	—																		
2. SR&T Flight Integration		—																	
3. SR&T Flight Test		—	—																
4. Space Tug Avionics Build				—	—	—	—	—											
5. First Space Tug Flight									—	—	—	—	—	—	—	—	—	—	—
APPLICATION																			
1. Design (Ph. C)				—	—	—													
2. Devl/Fab (Ph. D)							—	—	—										
3. Operations									—	—	—	—	—	—	—	—	—	—	—
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE				Δ														
NUMBER OF LAUNCHES									6	12	12	12	12	12	2	12	12	102

14. REFERENCES:

1. "Space Tug Avionics Definition Study" by General Dynamics
2. "Space Tug Definition Documents".
3. "Space Tug Baseline Requirement Definition Documents" by MSFC.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

The Avionic System for the full-capability Space Tug to be developed by NASA for initial operations in late 1983 will be driven by requirements of (1) performance to deliver 8000 pounds of payload into geosynchronous orbit and retrieve 3500 pounds, (2) mission duration up to 185 hours, (3) payload retrieval with potential for on-orbit servicing in the future, (4) autonomous flight operations, (5) Shuttle crew safety and mission success reliability (0.97 for all missions), and (6) 1983 IOC date for first operational flight. The 1978 Phase C/D timing will allos the Tug program to take maximum advantage of technology advances in the avionics implementation of these requirements to attain low system weight, power system capacity, sensors and software for [illegible], [illegible] update, checkout, redundancy and its managem[illegible].

The advanced technology nature of this avionics system has a significant influence on the system's total development cost. The advanced components selected for the baseline system definition were projections from research/technologies presently being pursued. From the current status of these technologies, the further technology development effort was defined that would be required before component design and development could be started or procurement specifications prepared. This is an essential first step in the whole process of getting an advanced hardware system designed, built, tested, qualified, and flown. There are two approaches for the accomplishment of these needed additional technology activities:

a. Perform these activities after Phase C/D starts. The overall Tug development schedule calls for Phase C/D to start in 1978, culminating with first operational flight in December 1983. The total DDT&E cost of avionics development for this approach was estimated to be $92.[illegible] million.

b. Perform these activities during the three-year period prior to the start of Phase C/D. The confidence gained by the early solution to problems and the proofing of techniques will reduce the risk during the actual component development phase and will reduce the total DDT&E cost of avionics development to $74.1 million.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 26

1. TECHNOLOGY REQUIREMENT (TITLE): Optical Correlator Landmark Tracker — PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Navigation, Guidance and Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Detailed design of the experimental procedures and an experimental test model, followed by design and fabrication of engineering and flight test models.

4. CURRENT STATE OF ART: Feasibility has been demonstrated. Significant studies have been made on individual components of a representative system for recognizing and tracking landmarks. HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

The technology calls for an automatic landmark tracker which can provide primary positional constraints more accurate than alternative onboard sensors, such as horizon trackers. The performance should also compare favorably with that of non-autonomous systems. The performance goal is to provide positional constraints having an uncertainty, due to landmark tracking operation, of 100 meters (3σ). The goal is not expected to represent an ultimate performance limit.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) The 100 meter positional constraint is based on a factor of 10 improvement over horizon sensing devices providing position errors of 2-10 km for relatively low altitude orbits.

b) Satellites/spacecraft requiring precision data for vehicle attitude determination and/or pointing control systems toward earth surface references could benefit from this technology.

c) This technology can reduce requirements for ground-based processing of data, simplify attitude determination techniques, reduce dependence on earth-based tracking stations, and aid earth-resources studies.

d) The level of technological maturity should be carried to a flight test experiment.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 26

1. TECHNOLOGY REQUIREMENT(TITLE): Optical Correlator Landmark Tracker PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

The option to an optical correlator landmark tracker is a video correlator utilizing an imaging device, such as an image dissector, and suitable recognition algorithms.

8. TECHNICAL PROBLEMS:

Experimental evaluation of real-time, optically excited devices for performing the input non-coherent optical to coherent optical interface function is needed.

9. POTENTIAL ALTERNATIVES:

1) Use of precision gyros and a stellar/landmark tracker for precision attitude determinition, pointing, and control.

2) Interferometric tracking of ground-based radar.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

A follow-on effort to Contract NAS1-12550 (A Landmark Recognition and Tracking Experiment for Flight on the Shuttle/Advanced Technology Laboratory (ATL) could be intiated.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 26

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 3 OF 3

Optical Correlator Landmark Tracker

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Design of demonstration test model																			
2. Simulation																			
3. Design, fabrication & test of engn. model																			
4. Design, fabrication & test of flight model																			
5. Flight test experiment																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		TOTAL
TECHNOLOGY NEED DATE																			
NUMBER OF LAUNCHES						1	1												2

14. REFERENCES:

1. Welch, J.D., "A Landmark Recognition and Tracking Experiment for Flight on the Shuttle/Advanced Technology Laboratory (ATL)," Final Report, Contract #NAS1-12550, July 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 27

1. TECHNOLOGY REQUIREMENT (TITLE): Video Correlator Landmark Tracker — PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Navigation, Guidance and Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of an autonomous video guidance, landing and imaging system.

4. CURRENT STATE OF ART: Feasibility de[illegible]nstrated

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

(1) A video correlator is employed in target acquisition and selection for earth resources imaging satellites.

(2) Video guidance is used for acquisition, tracking, rendezvous, and landing.

P L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

a) A real-time adaptive detection and tracking device is required that would have the ability to identify and track surface features of interest. The system should be immune to errors in the attitude control and pointing capability of the spacecraft.

b) The technique will allow a satellite imaging system to [illegible] [illegible] track landmarks, without human intervention, using a small amount of circuitry and an imaging sensor.

c) Future earth resources technology satellites, planetary landers, cometary and asteroid slow-flybys and rendezvous missions, and outer planet missions could benefit from this technology.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 27

1. TECHNOLOGY REQUIREMENT(TITLE): Video Correlator Landmark Tracker PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

The technology option to a video correlator is an optical correlator involving matching of observed landmarks with stored spatial filters for landmarks with stored spatial filters for landmark tracking.

8. TECHNICAL PROBLEMS:

a) Contrast effects
b) Color variations
c) Geomorphological variations
d) Field-of-view effects
e) Scan pattern variations
f) Recognition algorithms

9. POTENTIAL ALTERNATIVES:

1) A precision attitude, pointing, and control system consisting of precision gyros and a stellar/landmark tracker.

2) Interferometric landmark tracking by acquisition and tracking of ground-based radar.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Contract NAS1-13558 (Video Guidance, Landing, and Imaging System for Space Missions) could be expanded to extend the video guidance technology.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

None

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 27

1. TECHNOLOGY REQUIREMENT (TITLE): Video Correlator Landmark Tracker PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Optimize video guidance technique and apply technology		—																	
2. Develop flight hardware for earth resource satellite			—	—															
3. Ground Checkout				—	—														
4. Space checkout					—	—													
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE																		
NUMBER OF LAUNCHES					1	1												2

14. REFERENCES:

1) R.T. Schappell and G.R. Johnson: "Experimental and Simulation Study Results on the Development of a Planetary Landing Site Selection System." Paper No. 72-868 presented at AIAA Guidance and Control Conference at Stanford University, August 14, 1972 and published in the Journal of Spacecrafts and Rockets, Vol. 10, No. 4, April 1973.

2) R.T. Schappell, R.L. Knickerbocker, J.C. Tietz, C. Grant, and J.C. Flemming: "Video Guidance, Landing, and Imaging System (VGLIS) for Space Missions." Final Report on Contract NAS1-13558.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G. MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 28

1. TECHNOLOGY REQUIREMENT (TITLE): Optical Inertial Reference PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Spacecraft Attitude Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Spacecraft rotation sensor featuring hardware simplification, reduction in cost and ruggadization.

4. CURRENT STATE OF ART: Mechanical spun-mass gyro assemblies: complex and expensive.

HAS BEEN CARRIED TO LEVEL 7

5. DESCRIPTION OF TECHNOLOGY

The optical inertial reference will be an all-optical instrument having no moving parts. It will provide a full-time 3-axis inertial reference frame and will provide a direct digital measure of spacecraft rotation rates over the full range needed to provide control during thruster firing and maneuvers and to measure spacecraft attitude movement during limit cycle attitude control.

P. L. REQUIREMENTS BASED ON: [X] PRE-A, [ ] A, [ ] B, [ ] C D

6. RATIONALE AND ANALYSIS:

The optical inertial reference will incorporate a laser rotation sensor, which is a very simple device. A small laser is coupled to each end of a fiber optic strand wound in a coil on a small mandrel. Rotation about the axis of the coil alters the relative frequencies of the light passing through the fiber with, and against, the direction of rotation. Mixing and beat detection provide a direct digital measurement of rotation rate. Angular rotation sensitivity is a direct function of the effective area enclosed by the many-turn coil. This is not a "laser gyro" and is not limited by the mode pulling effects which have complicated laser gyro development.

The simplicity of the unit indicates a very low cost relative to the complex and delicate spun-mass assemblies now used. The low mass and inherently stable structures promise a very rugged and reliable device needing no special precautions during the launch period to survive. Power levels of a few watts or less are indicated.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 28

1. TECHNOLOGY REQUIREMENT(TITLE): Optical Inertial Sensor PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

The optical sensor could be fabricated using small and low power helium-neon lasers having very long reliable lifetimes which have been developed for laser gyro applications. Another, and possibly better, approach would use a fiber optic laser, directly coupled to the fiber optic strand. Integrated optics splicing and coupling techniques will be useful.

8. TECHNICAL PROBLEMS:

The principal technical problem appears to be obtaining single mode glass fibers of adequate length and quality. The fiber optic industry has demonstrated low loss (25 db/kilometer) glass fibers, and recently, single mode fibers.

9. POTENTIAL ALTERNATIVES:

A graded index, multimode fiber which compensates pathlength very accurately might be used. Multimode fibers using a means for attenuating higher order modes could be used.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

No significant programs in this area. Spun mass gyros are being "refined". Laser gyros are developing satisfactorily, but are complex, costly and have limited operating lifetime.

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

Requires successful blending of laser, fiber optic, integrated optics and electro-optic detection technologies.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 28

1 TECHNOLOGY REQUIREMENT (TITLE): PAGE 3 OF 3

Optical Inertial Sensor

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Functional Analysis		Δ																	
2. Lab Demonstration			Δ																
3. B.B. Design & Fab.			Δ																
4. Test & Development					Δ														
5.																			
APPLICATION																			
1. Design (Ph. C)								Δ											
2. Devl/Fab (Ph. D)										Δ									
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE						Δ											
NUMBER OF LAUNCHES																	

14 REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 30

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 3

Hard Lander Control System for Airless Planets

2. TECHNOLOGY CATEGORY: Guidance and Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase lifetime and reliability and change sensors for attitude control system.

4. CURRENT STATE OF ART: Sounding rockets incorporate similar systems although with more conventional sensors.

HAS BEEN CARRIED TO LEVEL 6

5. DESCRIPTION OF TECHNOLOGY

The control system must sense the actual deorbit velocity imparted by the lander retro-rocket, calculate the actual trajectory and flight path angle at impact, and control the lander attitude to produce zero angle of attack at impact. Accelerometers will be used to sense the deorbit velocity and gyros used for attitude references. The systems must function after storage during the cruise phase, which may be as long as 2 years.

P/L REQUIREMENTS BASED ON: [X] PRE-A, [ ] A, [ ] B, [ ] C/D

6. RATIONALE AND ANALYSIS:

a.) A closed loop attitude control system is needed to control the lander attitude at impact because the expected deorbit velocity errors are too large for a pre-programmed attitude control system.

b.) Hard lander missions to Moon and Mercury will be examined by a Science Advisory Group this year (1975) and considered for inclusion in all future orbiter missions.

c.) Without close control of impact angle of attack, the landers will not survive the landing shock.

d.) System performance can be demonstrated by air bearing tests and simulation. Lifetime can be demonstrated after storage.

TO BE CARRIED TO LEVEL 10

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 30

1. TECHNOLOGY REQUIREMENT(TITLE): Hard Lander Control System for Airless Planets PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Closed loop $\Delta\gamma$ control and fixed attitude, rather than open loop $\Delta\gamma$ and modified attitude.

8. TECHNICAL PROBLEMS:

Long term storage of high quality accelerometers and gyros.

9. POTENTIAL ALTERNATIVES:

a.) Very predictable deorbit motor ~1/2 % impulse predictability ~1/3 % thrust direction predictability.

b.) Use existing inertial measurement unit (IMU) which is far more expensive and heavy.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Surface Penetrators for Mars are being studied under RTOP 186-68-76. For Mars, however, the penetrator will use aerodynamic stability to provide low angle of attack at impact.

EXPECTED UNPERTURBED LEVEL 6

11. RELATED TECHNOLOGY REQUIREMENTS:

Space Storable liquid rocket motors may be needed to deorbit the bus spacecraft which carries penetrators to Mercury.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 30

1. TECHNOLOGY REQUIREMENT (TITLE): Hard Lander Control System for Airless Planets PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis, Simulation																			
2. Proof Test Design																			
3. Proof Test Simulation																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE						Δ												
NUMBER OF LAUNCHES										2			2			2		6

14. REFERENCES:

1. "Error Analysis of Penetrator Impact on Bodies Without Atmospheres" Report No. SAI 1-120-194-73, Science Applications, Inc.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 31

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 3

Video Inertial Pointing System for Shuttle Astronomy Payloads

2. TECHNOLOGY CATEGORY: Navigation Guidance and Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improve Pointing System Performance and Flexibility and Lower System Cost for Shuttle Attached Astronomy Payloads

4. CURRENT STATE OF ART: Use Multiple Image Dissector or Photomultiplier Star Trackers and/or Precision Gyros.

HAS BEEN CARRIED TO LEVEL 9

5. DESCRIPTION OF TECHNOLOGY

Current astronomy pointing systems use multiple Image Disector (ID) or Photo Multiplier Tube (PMT) star trackers and medium quality gyros, or a single star tracker and precision gyros. A video sensor can be used to provide multistar position data for three axis error signals and information for a CRT display of the pointing star field.

The CRT display at an oeprator's console will facilitate guide star/target acquisition and manual positioning of the experiment. Thus the video sensor can be used to reduce the number of optical sensors, lower the requirements on the gyro stabilization and provide additional system flexibility for shuttle-attached telescopes, where a payload specialist is available to assist in the pointing operations.

P L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

a. Investigations in astronomy require that it be possible to point at both bright and dim sources. Pointing at non-visible objects requires tracking the adjacent star field. Since the position of many dim targets is not precisely known with respect to the star field, the ability to view the adjacent field and complete the acquisition with an operator is crucial to the success of many astronomy missions. The use of a video type sensor can reduce the number of conventional star trackers and/or reduce the required quality of the gyro stabilization, provide human interaction.

b. All shuttle attached astronomy payloads will benefit from this technology including the Shuttle Infrared Telescope Facility (SIRTF) and the shuttle UV optical Telescope (SUOT).

c. This technology advancement will make possible a significant increase in the number of valuable astronomy observations due to the ability to point at faint stellar sources.

d. This technology advancement should be carried to an experimental system demonstration on an early shuttle flight. To gain maximum impact on the user community, the system demonstration should include pointing of an astronomical instrument.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 31

1. TECHNOLOGY REQUIREMENT(TITLE): PAGE 2 OF 3

Video Inertial Pointing System for Shuttle Astronomy Payloads

7. TECHNOLOGY OPTIONS:

1. CCD or CID versus conventional video sensors

   The CCD sensor being developed at JPL appears to have advantages over conventional video sensors.

8. TECHNICAL PROBLEMS:

1. Development of a videy sensor with adequate sensitivity and resolution.
2. Development of multi-star processing equations and techniques.
3. Development of optimum gyro filters with rapid settling time necessary for astronomy missions and good steady state noise response.
4. Development of guide star selection algorithms and manual control techniques.

9. POTENTIAL ALTERNATIVES:

SYSTEM ALTERNATIVES ARE:

1. Use multiple ID or FM star tracker and conventional gyro stabilization system.
2. Use a precision gyro stabilization system with periodic updates from a a single ID or FM star tracker.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

a. RTOP #506-19-15 "Video Inertial Pointing System for Shuttle Astronomy Payloads" Addresses the required technology and will carry it to level 6. The RTOP could be expanded for the level 7 demonstration.
b. RTOP #506-19-14 "Extended Life Attitude Control System for Unmanned Planetary Vehicles"

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

a. CCD Detector Improvements

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 31

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 3 OF 3

Video Inertial Pointing System for Shuttle Astronomy Payloads

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis	—	—	—			—													
2. Laboratory Demonstration	—	—																	
3. Aircraft Demonstration			—	—															
4. Shuttle Demonstration					—	—													
5.																			
APPLICATION																			
1. Design (Ph. C)					—														
2. Devl/Fab (Ph. D)						—													
3. Operations							—	—	—	—	—	—	—	—	—				
4.																			

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE							Δ										
NUMBER OF LAUNCHES																	

14 REFERENCES:

1. NASA/AMES C141AIRO INVESTIGATORS HANDBOOK

2. Deboo, G. J., Parra, G. T., and Hedlund, R.C., 1974 The AINOscope Stellar Acquisition System. Symposium on Telescope Systems for Ballon-borne Research.

3. Murphy, J. P. and Lowell, K. RR, 1974, The AIROscope Pointing and Stabilization System. Symposium of Telescope Systems for Ballon-borne Research.

4. JPL Memo #343-8-74-219, "Star Detection Capabilities of Charge Coupled Imaging Devices."

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 32

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 3

Attitude Control Flexible Spacecraft Configurations

2. TECHNOLOGY CATEGORY: Guidance, Navigation and Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Stabilization and control of large flexible structures through advanced techniques of modeling analysis including applications of observation theory, Kalman filtering and computer control.

4. CURRENT STATE OF ART: Current design practice for spacecraft with flexible appendages is to design control systems below frequencies of flexural modes.

HAS BEEN CARRIED TO LEVEL 9

5. DESCRIPTION OF TECHNOLOGY

There are classes of large flexible structures typical of Skylab and space stations where stability and reduction of motion due to flexibility are required. If pointing type instruments are appended to the main spacecraft, their orientation needs to be known and controlled, and their flexibility effects must be controllable and correctable. The disturbance environment, control system design and pointing accuracy depend on the mission. Technology is needed to establish systems and components that can achieve the needed pointing performance.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Communications antennas, earth pointing instruments, and precise optical devices must be controlled to accuracies beyond present capabilities.

(b) Higher efficiency of flexural mode control will result in lighter weight structures; hence, increased payload capability results.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 32

1. TECHNOLOGY REQUIREMENT(TITLE): PAGE 2 OF 3

Attitude Control Flexible Spacecraft Configurations

7. TECHNOLOGY OPTIONS:

There are two philosophies to achieve attitude control and stabilization of a flexible space vehicle configuration: (1) Control all the vehicle states to some bounded value, (2) control the rigid body to some bounded region and allow the structure to behave in an uncontrolled manner. The best engineering solution is an optimum mixture of these two philosophies.

8. TECHNICAL PROBLEMS:

1. Adequate strain gauges to measure deformations
2. Applications of state observer theory or Kalman filtering.

9. POTENTIAL ALTERNATIVES:

Spacecraft flexible appendages and couplings can be made stiffer;this results in increased weight and attendant reduction in pointing accuracies.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

NONE

EXPECTED UNPERTURBED LEVEL -

11. RELATED TECHNOLOGY REQUIREMENTS:

Development of sensors, and momentum storage devices.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 32

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 3 OF 3

Attitude Control Flexible Spacecraft Configurations

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis/Simulation		—	—																
2. Design				—	—														
3. Fabrication					—	—													
4. AND Test						—	—												
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE								Δ									TOTAL
NUMBER OF LAUNCHES																	

14. REFERENCES:

1. Attitude control of a flexible space vehicle by means of a linear state observer, British Aeronautical Journal, February 1975, Smith-Gill.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 33

1. TECHNOLOGY REQUIREMENT (TITLE): Figure control of Large Deformable Structures PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Guidance, Navigation and Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Surface and shape control of large flexible or furlable antenna structures and perhaps mirrors.

4. CURRENT STATE OF ART: Preliminary investigations of concepts materials for large space antennaes ongoing at Lewis, J.P.L., and Langley.

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY Figure or shape control of large flexible antenna structures is necessary to maintain efficiency and high gain for increased bandwidth applications. To provide shape control to fractions of a wavelength in the operating frequency region of interest will require advances in the theory of shape control and the technology of sensors and actuators.

P L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) The need for large lightweight antenna structures for increased communication capability has been established.

(b) In addition to optimizing gain characteristics of large antennas, optical telescopes and large laser mirrors will benefit from this technology.

(c) Thermal warpage, temperature gradients, and spacecraft and environmental disturbances will seriously degrade shape unless compensated.

(d) Because the lightweight structures will not be able to maintain figure (even if controlled) in a 1g environment, testing in space will be mandatory.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 33

1. TECHNOLOGY REQUIREMENT(TITLE): Figure control of Large Deformable Structures — PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Techniques for control of shape of large deformable structures will depend on mission characteristics. Control which utilizes a large number of sensors and actuators distributed over a flexible structure has been investigated for mirrors, but not in other areas. A unified theory for shape control of any flexible spacecraft configurations is an option.

8. TECHNICAL PROBLEMS:

1. Analysis of disturbance environment and shape control.

2. Actuators and sensors for shape control.

9. POTENTIAL ALTERNATIVES:

Increased structural weight with reduced dynamic range of sensors and actuators.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP 506-17-11, 506-17-15
Large erectable space structures and advanced concepts for spacecraft antenna structrues.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 33

11. TECHNOLOGY REQUIREMENT (TITLE): Figure control of Large Deformable Structures PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Analysis and Simulation																			
2. Activator and Sensor Design																			
3. Preliminary Gnd. Testing																			
4. Expt. Design and Fabrication																			
5. Space Checkout of System																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE								Δ										
NUMBER OF LAUNCHES									1	1	1							3

14. REFERENCES:

1. Research and Technology operating Plan Summary, Fiscal Year 75 National Aeronautics and Space Administration

2. A Technique for Designing Active Control Systems for Astronomers-Telescope Mirrors. Creedon J. F. and Howell, W. E. NASA TND-7090

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 34

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 3
High Accuracy Instrument Pointing System for Flexible Body S/C

2. TECHNOLOGY CATEGORY: Instrument Articulation Control

3. OBJECTIVE/ADVANCEMENT REQUIRED. Higher accuracy instrument stabilization and pointing control for planetary missions performed by Mariner class spacecraft.

4. CURRENT STATE OF ART: Spacecraft base-body stabilization is used as a reference to provide instrument LOS rate control and pointing accuracy.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

The approach to improving the science instrument pointing and scanning capability of planetary mission spacecraft will be to develop an instrument platform having a fast response, inertially stabilized instrument line-of-sight. Such a system would provide high accuracy (arc-second region) pointing for various imaging, telescope and astronomy experiments. The mechanization would consist of a high bandwidth controller utilizing a two-degree-of-freedom (2 DOF) gyro mounted on a 2 DOF platform with direct drive (gearless) actuators. By decoupling the instrument pointing system from the rest of the spacecraft, the need for image motion compensation for high resolution TV is eliminated. The system requirements are derived from the projected science pointing requirements for planetary missions over the next two decades. To provide the most cost effective approach, the implementation will be based on the low-cost, long-life, dry inertial reference unit (DRIRU) and the ELACS fault tolerant programmable attitude control electronics. Long term drift correction of the platform mounted gyro will be accomplished automatically using spacecraft celestial sensors.

P 1. REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

The requirement for this task is based on the fact that current Mariner/Viking class attitude and articulation control systems are performance limited and cannot satisfy the instrument pointing requirements for many future planetary and comet missions. Present Mariner/Viking class spacecraft can provide instrument three-sigma pointing control accuracies to 0.2 degree with minimum angular rates to .006 deg./sec. The time required to settle to these low rates following articulation of the science platform is typically several minutes for highly flexible spacecraft. Attempting to meet future science pointing requirements solely by improving the spacecraft attitude control performance places undue burden on the system design and can result in severe weight and cost penalties. Future planetary and comet missions require instrument pointing accuracies in the arc-section region. A need thus exists for a high accuracy, low cost instrument pointing system which can be controlled independent of the spacecraft attitude control system, and which is isolated from spacecraft-induced disturbances. Benefiting payloads are Mariner/Viking class planetary spacecraft and earth orbit satellites having flexible-body dynamics.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 34

1. **TECHNOLOGY REQUIREMENT(TITLE):** High Accuracy Instrument Pointing System for Flexible Body S/C

7. TECHNOLOGY OPTIONS:

a) Direct drive (gearless) actuators vs. geared motors

b) 2-DOF DRIRU vs single DOF gas bearing gyros

c) Programmable controller vs. wired logic machine

8. TECHNICAL PROBLEMS:

a) Determination of flexible structures dynamic parameters for establishing inputs to IPS.

b) Stabilization of high bandwidth controller.

9. POTENTIAL ALTERNATIVES:

a) Use of high cost single-DOF gas bearing gyros.

b) Offset pointing of instrument from optical sensor in the instrument FOV e.g., star image in telescope FOV.

c) Constrained structural design of S/C to "rigidize" the dynamics.

d) Development of suboptimal stochastic controller for spacecraft attitude controller.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

1) Advancements in state estimation and prediction of flexible structure interaction with control systems under RTOP #506-19-14

2) Long-life (fluid bearing) DRIRU (Dry Inertial Reference Unit) development under RTOP #506-19-14.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

Advancements in Fluid Bearing Technology for gyros to achieve longer life and very low noise. Improvements in speed, power, capacity of S/C Flight Computers. Also implied is use of micro processors and large scale IC's to reduce power, weight, size and improve reliability of system.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 34

1. TECHNOLOGY REQUIREMENT (TITLE): High Accuracy Instrument Pointing System for Flexible Body S/C

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. System Analyses		---																	
2. System Design		---	---																
3. Component Tasks			---																
4. Electronics & Software Tasks			---																
5. System Integration/Lab Demo			---	---															
APPLICATION																			
1. Design (Ph. C)				---															
2. Devl/Fab (Ph. D)					---														
3. Operations						---	---	---	---	---	---	---	---	---	---	---	---	---	
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		TOTAL
TECHNOLOGY NEED DATE				Δ															
NUMBER OF LAUNCHES						At	least		one	per	year								>12

14. REFERENCES:

NASA Outlook for Space Working Group V Report, "A Forecast of Space Technology 1980-2000." Section V, FC5-40, Spacecraft Stabilization and Control Systems

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 35

1. TECHNOLOGY REQUIREMENT (TITLE): Spacecraft Surface Force Control (SURFCON) and Attitude Control System PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Attitude and Translation Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Combined Attitude/Translation Control of Planetary S/C for Drag-Free Trajectory/Orbit Control and Precision Pointing of Science Instruments

4. CURRENT STATE OF ART: Components required are within state of art (pulsed plasma thruster, 10^{-11} g sensor, magnetic bearing reaction wheel, and flight computer)

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

The Surface Force Control concept is based on the fact that a spacecraft guided by a free-falling proof-mass shielded from all non-gravity forces can be controlled to follow a true gravitational trajectory. The spacecraft is compelled to center itself on the proof-mass by a control system which senses the relative displacement between the two bodies in three translational degrees-of-freedom and actuates thrusters to cancel all spacecraft surface forces producing non-gravitational accelerations. The approach will be to develop the control concept and mechanization which combines a unique sensor for detecting proof-mass position (developed by Stanford) with advanced pulsed plasma microthrusters and magnetic bearing reaction wheels (in development at JPL) for a functionally integrated Attitude Control and SURFCON System. The sensor for a SURFCON System has been flight proven on the TRIAD Navigation satellite (1972) and the microthruster on the LES-6 communications satellite (1968). In the near future, advanced Transit Navigation satellites, the LES 8/9, and the Synchronous Meteorological satellite will also be using the sensor and microthruster devices directly applicable to the missions.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Future planetary and solar probe missions have fundamental science requirements that cannot be satisfactorily met by current spacecraft attitude and translation control system designs. Specifically, there are many new planetary science experiments proposed for both inner and outer planets missions of the 1980's which require that the spacecraft follow a purely gravitational orbit/trajectory for highly accurate relativistic, gravimetric, and atmospheric physics measurements, as well as low orbit stationkeeping. Because of its superior radio system, such radio science experiments could best be accommodated using a Mariner class spacecraft with an appropr' te Attitude Control and Surface Force Control (SURFCON) System. A need thus exists for a functionally integrated Attitude Control and SURFCON System which provides the necessary pointing accuracy and at the same time provides "drag-free" trajectory/orbit control thereby freeing the spacecraft from all non-gravitational forces.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 35

1. TECHNOLOGY REQUIREMENT(TITLE): Spacecraft Surface Force Control and Attitude Control System PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

None.

8. TECHNICAL PROBLEMS:

None.

9. POTENTIAL ALTERNATIVES:

Use tri-axial low-g force balance accelerometers rather than Stanford Floating Ball Displacement Sensor, accelerometer calibration errors may compromise performance.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

The advanced Transit Navigation satellite program will use the 10^{-11} g sensor; and the LES-8/9 and SMS programs will use the pulse plasma thrusters. JPL is developing the Magnetic Bearing Reaction Wheel under RTOP #506-19-14.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

Continued development of the Magnetic Bearing Reaction Wheel.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 35

1. TECHNOLOGY REQUIREMENT (TITLE): Spacecraft Surface Force Control and Attitude Control System PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. System Analyses		---																	
2. System Design		---	---																
3. Component Tasks			---	---															
4. System Integ./Lab Demo				---	---														
5. Flight Verification Experiment					---	---													
APPLICATION																			
1. Design (Ph. C)						---	---												
2. Devl/Fab (Ph. D)							---	---											
3. Operations									---	---	---	---	---	---	---	---	---		
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE					▲													
NUMBER OF LAUNCHES									1	1	1	1	1	1	1	1	1	9

14 REFERENCES:

1) "Description of a Surface Force Control System for Planetary Probes," JPL EM 344-493, E. Mettler, 12/26/74.

2) "Radio Science Experiments on a Solar Probe," JPL IOM 391.4-688, J.D. Anderson, 2/19/75.

3) "Impact of Future Attitude Control Systems on Celestial Mechanics Experiments," JPL IOM 391.4-671, J. D. Anderson, 11/26/74.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 36

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 4

Radiation Attitude Control for Extended Life Planetary Missions

2. TECHNOLOGY CATEGORY: Guidance and Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Extend useful Mission life of Spacecraft Control by using Radioisotope Thermal Generator (RTG) Radiation

4. CURRENT STATE OF ART: Recent flight experience with Mariner 10 demonstrated advantage of using solar radiation for attitude control

HAS BEEN CARRIED TO LEVEL 7

5. DESCRIPTION OF TECHNOLOGY

During interplanetary and deep space flight, the radiation from RTG's impinging on vehicle structure is usually the primary disturbance torque to attitude control. If it is treated as a disturbance, it inevitably causes the use of propulsion expendables. Using the RTG Radiation for a control torque, allows significant savings in expendables.

(Continued on Page 4)

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Fuel for attitude control propulsion can be conserved through the use of the radiation properties of RTG's. It seems theoretically possible to significantly extend the attitude control life of a vehicle for Outer Planet missions, enhancing the potential for penetrating deep space beyond. The advantages to the acquisition of scientific information are clear. It is also quite fortunate that valuable spacecraft system design information exists for the application of such a scheme for a possible Mariner Jupiter Uranus (MJU) Missions. It is expected that there would be significant fallout from the study so that such an implementation would be available in a timely fashion to benefit an MJU mission.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 36

1. TECHNOLOGY REQUIREMENT(TITLE): PAGE 2 OF 4

Radiation Attitude Control for Extended Life Planetary Missions

7. TECHNOLOGY OPTIONS:

1. Continue tradeoffs between added consumables vs added mission life.

8. TECHNICAL PROBLEMS:

1. It must be fail safe. Clearly there must be minimal possibility of shortening a mission, e.g., creating a large disturbance torque.
2. The RTG radition must be understood as well as possible (e.g., variation with time).
3. The effect on vehicle thermal properties, including the RTG case temperature effect and vehicle thermal control, must be studied.
4. Short range effects must be evaluated, such as solar radiation pressure while close to the sun.

9. POTENTIAL ALTERNATIVES:

Use solar pressure flippers to compensate disturbance torques.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

None.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 36

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 3 OF 4

Radiation Attitude Control for Extended Life Planetary Missions

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Candidate Baseline Passive Control			Δ																
2. Candidate Baseline Passive Control			Δ																
3. Complete Study				Δ															
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE				Δ														
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 36

1. TECHNOLOGY REQUIREMENT (TITLE): Radiation Attitude Control for Extended Life Planetary Missions

The immediate objective of the program is to study the nature, magnitude, and variation of radiation developed by RTG's for the purpose of using it to extend the attitude control life of three axis stabilized vehicles. At the conclusion of that phase, the concept will be extended to study implementations for spin stabilized vehicles. The immediate objective will be divided into two steps. The first step will serve several useful purposes. Even though it would not provide the significant benefit of an active onboard control, it is the simplest approach, and could be implemented as such if system, schedule and cost tradeoffs favored it. It would be an early fallout in the program. Equally important, it would establish the necessary initial conditions for an active, onboard control. Active control is best implemented by developing bi-directional torques about a nominal null point.

The second step will be to develop active control techniques such that other disturbances from onboard or environmental sources may be controlled. The objectives will include a study of the deep space flight mode where application is most favorable because of the benign environment. However, planetary orbiters will also be studied for possible application. The goals will be established so that the fallout from both the passive and active control developments would be available to an MJU mission.

At the conclusion of the three axis control development, the study will be extended to include spin stabilized vehicles. In general the goals will be the same as the three axis task. First develop passive techniques for control purposes. Flight experience and mission study information does not exist in the magnitude available for three axis control. Some preliminary mission analysis must precede the development of control techniques.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 37

1. TECHNOLOGY REQUIREMENT (TITLE): PAGE 1 OF 3

Fluid Momentum Generator

2. TECHNOLOGY CATEGORY:

3. OBJECTIVE/ADVANCEMENT REQUIRED: Demonstrate a fluid rotor momentum generator wuitable for spacecraft application. Concept employs a circular tube filled with a low-viscosity magnetic fluid driven by a linear induction motor LIM

4. CURRENT STATE OF ART: Category 4. Both fluid rotor momentum generators and magnetic fluids have been demonstrated, but the combination has not been investigated for space control use.

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Future missions will require extremely low torque jitter, better than can be accomplished with ball bearings. One possible solution is a magnetically suspended metal rotor, but this is a complex and expensive approach. The fluid rotor is potentially simple and inexpensive. Having no moving parts, other than fluid, it is potentially reliable.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Jitter-free torquers with high reliability are required for future, high-precision attitude control systems for science and applications missions.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 37

1. **TECHNOLOGY REQUIREMENT(TITLE):** Fluid Momentum Generator — PAGE 2 OF 3

7. **TECHNOLOGY OPTIONS:**

It may be worthwhile to provide a family of fluids for different applications.

8. **TECHNICAL PROBLEMS:**

a. Magnetic fluid development.

b. Linear Induction Motor Development.

9. **POTENTIAL ALTERNATIVES:**

a. Magnetically suspended rotors.

b. Improved conventional ball bearings.

10. **PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:**

Magnetic fluid technology research for other uses.

EXPECTED UNPERTURBED LEVEL 4

11. **RELATED TECHNOLOGY REQUIREMENTS:**

None.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 37

1. TECHNOLOGY REQUIREMENT (TITLE): Fluid Momentum Generator PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Fluid Development			---	---															
2. Motor Development				---	---														
3. Component Design					---	---													
4. Evaluation						---													
5. Test Flight							Δ												
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL
TECHNOLOGY NEED DATE							Δ										
NUMBER OF LAUNCHES																	

14. REFERENCES:

None.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 38

1. TECHNOLOGY REQUIREMENT (TITLE): Measurement and Control of Long Base Line Structures PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Precision measurement and control of long base line structures for interferometry

4. CURRENT STATE OF ART: Structural design permits lower accuracy interferometry.

HAS BEEN CARRIED TO LEVEL 7

5. DESCRIPTION OF TECHNOLOGY

To provide accurate interferometric measurement requires precise knowledge and stability of long base line structures. These structures may or may not be physically connected; therefore, various control techniques from structural control to orbital station keeping must be used.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

There exists a class of space experiments which require extremely long base line interferometry. These base lines vary from meters to earth/moon distances and operate from optical to RF wavelengths. This tech ology is also applicable to search and rescue missions for earth vehicles, i.e., aircraft, ships, ground stations, etc. Accurate interferometers are a promising means of accomplishing this using minimal equipment on the ground mobile platforms. Accurate line of sight information from a master and two slave interferometer locations can be used to locate a ground target. Locations of the interferometer elements can be derived from onboard measurements or using fixed ground beacons.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 38

1. TECHNOLOGY REQUIREMENT(TITLE): Measurement and Control of Long Base Line Structures PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Structure control vs. free-flying interferometer elements.

8. TECHNICAL PROBLEMS:

Measurement of baseline to order of 1 part in 10^{-8}.
Structural Control.
Precision station keeping.

9. POTENTIAL ALTERNATIVES:

Non-optimum reliance on structural design alone.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Analyses of flexible-body spacecraft control systems.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 38

1. TECHNOLOGY REQUIREMENT (TITLE): Measurement and Control of Long Base Line Structures — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Development of Measurement Tech.					---	---													
2. Development of Orbit Keeping Tech.							---	---											
3. Structural Control Technology									---										
4. Short Base Line Interelements										---	---								
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE											Δ							
NUMBER OF LAUNCHES																		

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 39

1. TECHNOLOGY REQUIREMENT (TITLE): Magnetic Large Array Assembly and Shape Management PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Attitude control structures

3. OBJECTIVE/ADVANCEMENT REQUIRED: Shape control of large arrays

4. CURRENT STATE OF ART: No proven technology exists for non-mechanical control of large arrays

HAS BEEN CARRIED TO LEVEL 0

5. DESCRIPTION OF TECHNOLOGY

Because of the weak forces and moments involved, weak magnetic coupling and torquing devices may be adequate for active coupling and shape control of large arrays.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

In order to make large space arrays feasible it is important to reduce weight, simplify deployment, and control the shape to high accuracy. Active magnetic coupling of light weight plates is one possibility that deserves investigation. The array shape could be surveyed by a laser beam and computer commands issued to the elements for shape control.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 41

1. TECHNOLOGY REQUIREMENT (TITLE): Space Teleoperator Technology PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Teleoperators

3. OBJECTIVE/ADVANCEMENT REQUIRED: To define and develop experimental and prototype teleoperator systems for earth, lunar and planetary orbit and surface operations.

4. CURRENT STATE OF ART: Stepwise control of teleoperators under direct visual feedback with limited communication time lag is within the state-of-the-art.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Teleoperators represent an integration of numerous specific technologies including sensors, manipulators and end effectors, control and display devices and computers to enhance the capabilities of man by the extension of his sensory and motor factors. Critical parameters include the split of activities between the man and the supervisory computer, the interaction of man with the display and control devices, the ability of the manipulator to provide the required dexterity, and the ability to accommodate varying and potentially long time delays.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Where man is involved, for economic, safety, and technical reasons, it is desirable that his capability to conduct space operations be enhanced and extended where possible. Teleoperator systems offer a great potential for doing this. Functioning as extensions to spacecraft; as free flying vehicles remotely operated from the Shuttle, space station, on the ground; or as surface vehicles remotely operated from earth, the teleoperator will augment the human in performing a number of useful tasks which otherwise would not be possible.

TYPICAL TELEOPERATOR APPLICATION - It is not expected that the teleoperator will be used in every circumstance but that it becomes a candidate for missions where the return is effective, such as:

1. Space Shuttle Payloads/Automated Satellites
   Inspection, Deployment, Retrieval, Maintenance/Repair, Resupply assembly/mating.
2. Surface Exploration: Sample Handling, Autonomous Navigation, Obstacle Avoidance, Control in Presence of Large Time Delay.

TYPICAL MISSION CANDIDATES: HE-01-A, AP-01-A, LS-02-A, OP-04-A, CN-51-A, EO-56-A, CN-54-A, CN-58-A, EO-09-A, EO-57-A, EO-05-S, AP-06-S, AS-01-A, ST-01-A. Radio Astronomy Telescope (200m Dia.) Microwave Power Transmission (100m Dia.)

TO BE CARRIED TO LEVEL __

1. TECHNOLOGY REQUIREMENT(TITLE): Space Teleoperator Technology

7. TECHNOLOGY OPTIONS:

The technology options include: Different manipulators, end effectors and controllers; various manipulator-based sensors (proximity, tactile, torque/force) with varying degrees of resolution; various control input capabilities; various mobility units for manipulator transportation and positional (Free flying spacecraft, roving vehicles, etc.); various information feedback and display devices; and various digital processors and related programs.

8. TECHNICAL PROBLEMS: The major technical problems are:

a.) Development of relevant sensors and displays is only in a preliminary stage. This is particularly true for manipulator tactile, force and proximity sensors.
b.) The proper methods for dividing work and responsibility between man and the computer has not been investigated. A thorough analysis of the role of various digital processors and control methods for remote manipulation is missing.
c.) The development of manipulators with sufficient dexterity still must be achieved.
d.) In general, the short time history of and very limit d experiments with relevant breadboard systems represents a problem.

9. POTENTIAL ALTERNATIVES: The obvious potential alternatives are:

a.) Send man with his own manipulative capabilities where such capabilities are needed to achieve the goals of the mission.
b.) Let remote control be performed using the technology of yesterday (stepwise, rigid, inflexible, risky, tiring operations which in addition would require costly ground support.)

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP #970-83-20 "Teleoperator Technology Studies for Communication Delayed Controls."
RTOP #970-63-20 "Technology for Remote Manned Control for Payload Servicing."

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

Special sensors (proximity, tactile, force/torque technology; miniaturized digital processor technology; interactive software technology; special purpose display technology; task and motion analysis technology; performance evaluation technology; and man-machine interface component technology.

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 41

1. TECHNOLOGY REQUIREMENT (TITLE): Space Teleoperator Technology — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Components Development																			
2. System Integration										TOBE - Teleoperator Orbiter Bay Experiment									
3. Experiments																			
4. Function Tests										EOTS - Earth Orbital Teleoperator System									
5. Simulated Space Flight Tests & Documentation																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations, Version I						Δ TOBE			Δ EOTS										
4. Operations, Version II																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
Operational TECHNOLOGY NEED DATE								Δ										
NUMBER OF LAUNCHES								15	26	32	41	53	55	58	61	64	68	473

14. REFERENCES:

1. Bejczy, A. K., "Environment-Sensitive Manipulator Control," Proceedings of the 1974 IEEE Conference on Decision and Control, November 20-22, 1974, Phoenix, Arizona.
2. Bejczy, A. K., "Advanced Automation Systems for Manipulator Control Technology Survey," JPL AST Report 760-77, December 15, 1972.
3. Bejczy, A. K., "Remote Manipulator Systems, Technology Review and Planetary Operation Requirements," JPL AST Report 760-77, July 1, 1972.
4. Heer, E., ed., "Remotely Manned Systems --Exploration and Operation in Space Proceedings of the First National RMS Conference," California Institute of Technology Publication, Pasadena, California, 1973.
5. "Summary Proceedings of the Second Conference on Remotely Manned Systems, Technology and Applications," USC, Los Angeles, California, June 9-11, 1975.
6. Study Results from NASA contracts: NAS8-27021, 27895, 29153, 29024, 28298, 28055, 30266, and 31290.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 42

1. TECHNOLOGY REQUIREMENT (TITLE): Supervisory Control of Remote Manipulators PAGE 1 OF 4

2. TECHNOLOGY CATEGORY: Teleoperators/Robots

3. OBJECTIVE/ADVANCEMENT REQUIRED: Increase efficiency, versatility, and safety, and decrease cost and complexity, in performing remote manipulative operations in space with special emphasis on "humanizing" (cont'd on pg. 4)

4. CURRENT STATE OF ART: Stepwise control of remote manipulators under direct visual feedback and with no communication time lag is (cont'd on pg. 4)

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Supervisory control deals with the allocation of control between the man and the manipulator. Efficient, versatile, and safe control performance of remote manipulation depends to a great extent on the allocation of control functions between operator and control computer. Distribution of control between man and computer in turn depends on the following basic factors: (a) The mechanical and servo characteristics of the manipulator and end effector. (b) The components of the manipulation-related visual and non-visual information systems including displays and manipulator-based sensors. (c) Characteristics of task categories and properties of manipulator motion phases. (d) Completeness of task description in logical and arithmetic terms matching the capabilities of the remote manipulator control system which also includes man in the control loop. (e) Miniaturization of sensory and digital data handling devices. (f) The structure and interactive capabilities of the control software. The state of the art can be reviewed in Refs. 1 to 5.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

(a) Novel and efficient allocation of manipulator control functions between man and computer will be required for the shuttle-attached remote manipulator systems, free-flying teleoperators, and planetary/lunar surface explorers. (b) All earth orbital and planetary/lunary surface missions which require manipulative capabilities will benefit from supervisory control capabilities. (c) Efficiency, versatility, and safety in performing manipulative operations in space with or without the constraints of communication time lag is directly proportional to the capabilities of a supervisory control system. (d) This technology advancement should first be carried to an experimental demonstration for relevant and true space flight conditions simulated on earth. Then, a first level version of this technology should be implemented for an unmanned surface explorer and/or for an early shuttle flight.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 42

1 TECHNOLOGY REQUIREMENT(TITLE): PAGE 2 OF 4

Supervisory Control of Remote Manipulators

7. TECHNOLOGY OPTIONS:

The technology options include: different manipulators and end effectors; various manipulator-based sensors (proximity, tactile, torque/force) with varying degrees of resolution; various control input capabilities; various information feedback or display devices; various digital processors and related programs.

8. TECHNICAL PROBLEMS:

The major technical problems are: (a) Short-time history of and very limited experiments with relevant bench model or breadboard systems. (b) Development of relevant sensors and displays is only in a preliminary stage. (c) Motion and control related human factors is insufficient. (d) A thorough analysis of the role of various digital processors and control schemes for remote manipulation is missi . (e) Lack of development and/or application of miniaturized sensors and ditital processors.

9. POTENTIAL ALTERNATIVES:

The obvious potential alternatives are: (a) Send man with his own manipulative capabilities where such capabilities are needed to achieve the goals of the mission(s). (b) Let remote control be performed using the technology of yesterday (stepwise, rigid, inflexible, risky, tiring operations which in addition require costly ground support).

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

RTOP #970-83-20-41 'Remote Manipulator System Control and Man-Machine Interface" can be expanded to include demonstration tests under relevant space flight conditions simulated on earth.

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

Special sensors (proximity, tactile, force/torque) technology; miniaturized digital processor technology; interactive software technology; special purpose display technology; task and motion analysis technology performance evaluation technology; man-machine interface component technology.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 42

1. TECHNOLOGY REQUIREMENT (TITLE): Supervisory Control of Remote Manipulators

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	
TECHNOLOGY																			
1. Components Development	—	—	—																
2. System Integration	—	—	—	—	—														
3. Experiments	—	—	—	—	—	—													
4. Function Tests			—	—	—	—	—												
5. Simulated Space Flight Tests & Documentation					—	—	—	—											
APPLICATION																			
1. Design (Ph. C)								—	—	—									
2. Devl/Fab (Ph. D)									—	—	—								
3. Operations, Version I									—	—	—	—	—						
4. Operations, Version II													—	—	—	—	—	—	

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE								▲										
NUMBER OF LAUNCHES								15	26	32	41	53	55	58	61	64	68	473

14. REFERENCES:

1. Bejczy, A.K., "Environment-Sensitive Manipulator Control," Proceedings of the 1974 IEEE Conference on Decision and Control, November 20-22, 1974, Phoenix, Arizona.
2. Bejczy, A.K., "Advanced Automation Systems for Manipulator Control Technology Survey," JPL ATS Report 760-83, December 15, 1972.
3. Bejczy, A.K., "Remote Manipulator Systems, Technology Review and Planetary Operation Requirements," JPL AST Report 760-77, July 1, 1972.
4. Heer, E., ed., "Remotely Manned Systems--Exploration and Operation in Space," Proceedings of the First National RMS Conference, California Institute of Technology Publication, Pasadena, California, 1973.
5. "Summary Proceedings of the Second Conference on Remotely Manned Systems, Technology and Applications," USC, Los Angeles, California, June 9-11, 1975.

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 42

1. TECHNOLOGY REQUIREMENT (TITLE): Supervisory Control of Remote Manipulators PAGE 4 OF 4

Continued from page 42, page 1 of 4:

3. OBJECTIVE/ADVANCEMENT REQUIRED: the man-machine control and information

4. CURRENT STATE OF ART: within the state of the art. On the other hand, supervisory control of remote manipulators is typified by preliminary bench or breadboard systems and experiments (reviewed in Refs. 1 and 2) and as of 1975.

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 43

1. TECHNOLOGY REQUIREMENT (TITLE): Satellite Servicing — PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Guidance, Navigation & Control

3. OBJECTIVE/ADVANCEMENT REQUIRED: Provide technology for Satellite Teleoperator Common interface equipment development.

4. CURRENT STATE OF ART: Preliminary economic and operational guidelines developed through advanced mission studies.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Technology development to determine optimal interface hardware conceptual designs to enhance satellite servicing capability and verified through on-orbit experiments.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☒ B, ☐ C D

6. RATIONALE AND ANALYSIS:

For economic, safety, and other technical reasons, it is desirable to enhance and extend capabilities to operate in space. Remote controlled satellite servicing offers a great potential for providing this capability.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 44

1. TECHNOLOGY REQUIREMENT (TITLE): Multi-Purpose Panel PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Life Sciences

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop a programmable alphanumeric display.

4. CURRENT STATE OF ART: Feasibility and practicality has been shown.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Develop an addressable alphanumeric display for flight and ground based control and display stations which will permit rapid changes in panel nomenclature and control outputs.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

There is presently a need for a flexible control panel that can be programmed to satisfy the requirements of many unrelated but similar systems. The need for this type of technology is required where panel space is limited and would compromise the prime objective of an experiment or subsystem.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT　　NO. 44

1. TECHNOLOGY REQUIREMENT (TITLE): Multi-Purpose Panel　　PAGE 2 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Flight Concept																			
2. Proto/Flight Design																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE			▽															TOTAL
NUMBER OF LAUNCHES																		

14. REFERENCES:

Contract NAS3-31286
Phase I Study Report

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 44

1. TECHNOLOGY REQUIREMENT (TITLE): Multi-Purpose Panel PAGE 3 OF 3

During the ATM Control and Display effort in the Skylab Program, some shortcomings of a large scale dedicated C and D panel were encountered. The impact of panel changes resulting from refinements of the various subsystems was of primary concern. The modification of panel wiring and nomenclature at the many system development stages was both time consuming and costly. Another significant problem was human error created by grouping many similar experiments together. The operator would tend to be confused by nearly identical controls located near each other.

To overcome these problems, a Multi-purpose Panel is being considered. Under this concept, a large scale control and display for a number of similar subsystems or experiments would be replaced by a single small scale panel capable of being programmed.

The fabrication of a Multi-purpose Panel is made practical at this time by a number of recent developments. The evólution of electronic display technology in recent years now allows us to seriously consider the concept of changeable panel nomenclature. The maturation of miniaturized electronic and memory devices then provides the flexibility, compactness, and economy required to consider the Multi-purpose Panel as a viable alternative to dedicate control and display panels. The Multi-purpose Panel is compatible with the trend toward sophisticated Data Management Systems where digital address and multiplexing are central features. Finally, projected as a concept to be applied in the Space Shuttle Payload Station, the Multi-purpose Panel will economically provide the flexibility for such a mission.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 45

1. TECHNOLOGY REQUIREMENT (TITLE): End Effector and Sensors PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Space Teleoperator Technology Requirement

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of end effectors/sensors of near human dexterity and sensitivity.

4. CURRENT STATE OF ART: Basically a parallel jaw design lined with friction type material for grasping and limited feedback sensors.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

The following technical investigations and design goals should be considered.

a. End effector/task trade studies.

b. Initiate design effort for an end effector from the trade studies.

c. Conduct technical design effort to integrate a tactile sensor in the end effector, and software for handling time delay conditions.

d. Low weight, minimum profile.
e. Jaw closure plus rotation.
f. Universally adaptable to manipulator.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C D

6. RATIONALE AND ANALYSIS:

Optimum end effector design is highly dependent on the task for which it is to be used. Efforts to develop a universal end effector has been consistently unsuccessful. The usual end effector being utilized at present is one of parallel jaws with contours and lined with a material to provide a type of friction necessary for grasping and holding. Some work has been conducted in adapting a standard interface with a set of common tools opening/closing and rotary action. Tactile, proximity, etc., sensors to improve the effectiveness of the devices are in various states of technology; however, none of those have been successfully integrated.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 46

1. TECHNOLOGY REQUIREMENT (TITLE): Teleoperator Controllers PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Space Teleoperator Technology Requirement

3. OBJECTIVE/ADVANCEMENT REQUIRED: Development of a single controller for 6 Degree-of-Freedom plus end effector, adaptable to use for both manipulator and remote vehicle control.

4. CURRENT STATE OF ART: Inadequate for accomplishment of the above with crosstalk between command signals, size constraints on human performance.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Technology should be developed to meet the following design goals.

a. Single controller for 6 DOF plus end effector.
b. Minimum crosstalk between command signals.
c. Small size.
d. High resolution, continuous output.
e. Control logic adapted to manipulator/task.
f. Force control modes.
g. Adaptable to use for both manipulator and remove vehicle control.
h. Maximize human performance capability.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

At present the controllers available for use with remotely operated 6 DOF manipulators suffer from many shortcomings. Among these are:

a. Size.

b. Crosstalk between command signals.

c. Number controllers.

d. Constraints on human performance.

No acceptable controller exists for dexterous manipulators to be used for servicing tasks in a remote space environment.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT — NO. 47

1. TECHNOLOGY REQUIREMENT (TITLE): Wrist Mechanisms — PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Space Teleoperator Technology Requirement

3. OBJECTIVE/ADVANCEMENT REQUIRED: Light weight, 3 Degree-of-Freedom (DOF) with common pivot point.

4. CURRENT STATE OF ART: Presently wrist designs having 3 DOF, have series joints to provide freedom.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Develop a 3 DOF wrist with common pivot meeting following goals:

- a. Joint ordering: Pitch/yaw/roll or yaw/pitch/roll.
- b. Light weight: 10% of manipulator arm or less.
- c. Capable of 15 ft. lbs. torque in each axis.
- d. Universally adaptable to manipulator.
- e. Integration of wrist force sensor.
- f. Minimum power transfer across joints.
- g. Universally adaptable to end effector & sensors.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

There are certain characteristics of the manipulator configuration which make the arm control logic simpler and easier to implement. These concern the ordering of the joint motions and the relationships between the final three degrees-of-freedom. At present, there is no wrist mechanism meeting the goals of a remote operated manipulator. Such a device should meet the above goals.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 48

1 TECHNOLOGY REQUIREMENT (TITLE): Miniature TV Camera PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Space Teleoperator Technology Requirement

3. OBJECTIVE/ADVANCEMENT REQUIRED: Miniature TV camera for compatible interface/mounting on manipulators.

4. CURRENT STATE OF ART: Currently TV cameras are too large for compatible interface/mounting on manipulators.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Advance TV technology for reducing the size of the TV camera to meet the following requirements:

a. Size - 36 $in.^3$
b. Weight - 1,516
c. Capable of mounting on manipulator arm
d. Zoom, self-focussing lens, wide angle to telephoto
e. Integrated light source
f. Automatic parallax adjustment
g. Useable as a stereoptic pair
h. Color adaptable
i. Automatic light intensity control
j. Maintain operator performance requirements

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6 RATIONALE AND ANALYSIS:

Present camera technology will meet the general requirements of the teleoperator system except on the size and weight of the on-board units. Upon taking action to reduce size and weight, it may be necessary to employ different sensor and electronics technology. These techniques are generally available; however, no unit is available that will, with a single camera, meet the complete requirement. Additional technology is required in the design and assembly of a camera which will meet these requirements.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 49

1. TECHNOLOGY REQUIREMENT (TITLE): Image Enhancement PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Space Teleoperator Technology Requirement

3. OBJECTIVE/ADVANCEMENT REQUIRED: Improve and clarify poor images resulting from blurring, washout and poor contrast of video signals.

4. CURRENT STATE OF ART: The technology is basically available but requires refinement and development into flight configuration.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

1. Image Enhancement

Operator viewing of teleoperator television cameras requires sharp imaging of the target. Poor images arise from many sources resulting in poor contrast, washout, blurred details, etc. There a e a number of techniques which can be utilized in providing a better image under given circumstances. Generally, the methods are based on processing the video signal data such as to eliminate the undesirable effects. The time required and the complexity of the processor depends on the nature of the original image and the method employed.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The requirements of the teleoperator are generally as follows for video signals:

a. Near real time processing cycle: 1-2 sec.

b. Ease of control by operator.

c. Increase contrast and sharpen edges.

d. On-site processing desirable.

e. Minimum processor complexity - may be dedicated.

TO BE CARRIED TO LEVEL ___

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 50

1. TECHNOLOGY REQUIREMENT (TITLE): Video Signal Communication PAGE 1 OF 1

2. TECHNOLOGY CATEGORY: Space Teleoperator Technology Requirement

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop communication techniques adequate for handling 3 video & 1 telemetry signals in a banwidth less than 10 MHz.

4. CURRENT STATE OF ART: Inadequate - Three 4.5 MHz video signals plus telemetry on 10 GHz R.F. carrier is present state of art.

HAS BEEN CARRIED TO LEVEL ___

5. DESCRIPTION OF TECHNOLOGY

Develop communication techniques adequate to meet the following requirements.

a. Place three 4.0 MHz video signals plus telemetry in a bandwidth less than 10 MHz.

b. Display a stereo video signal which can be used by the operator (meet his performance requirements).

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

The visual sensor/system provides about 90% of the sensed information input to the operator of the teleoperator. For some tasks visual sense requirements can be met with a single well placed monoptic television. Additional tasks require that the television camera be moveable. Further some tasks require two television cameras operating simultaneously. The most exacting servicing tasks require a stereoptic display. The last requirement can be met with a pair of cameras operating as a stereo pair plus a single camera giving monoptic image from a different direction.

The communication system requirements become increasingly difficult as the number of cameras increase. Color capability increases it further.

TO BE CARRIED TO LEVEL ___

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-1
PAGE 1

1. REF. NO. ________ PREP DATE ________ REV DATE ________ LTR ____
CATEGORY Guidance, Navigation & Control

2. TITLE Low Cost Navigation Indepdent of NASA Tracking Facilities

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
6	6	7

There exists several widespread navigation nets for aircraft use around the world. The most notable are DME and Omega. These may be usable for spacecraft navigation on an autonomous basis and therefore relieve the NASA tracking net of some of its work load. Such a system would provide moderately accurate, near autonomous operation for a large class of earth observation satellites (particularly survey and monitoring missions). What is presently required is an experiment to assess the capabilities of these ground systems.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1981
PAYLOAD DEVELOPMENT LEAD TIME 1 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ________

TECHNICAL BENEFITS Lower operational costs through autonomous operation and the use of existing facilities in a new way.

POTENTIAL COST BENEFITS ?

ESTIMATED COST SAVINGS $?

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS The technical risks are very low. The first cost is to fly a survey mission using modified aircraft navigation equipment to determine signal strength, potential accuracy and problems unique to space.

REQUIRED SUPPORTING TECHNOLOGIES ________

7. REFERENCE DOCUMENTS/COMMENTS ________

FT (TDR 11 7 75

TITLE Low Cost Navigation Independent of NASA Tracking Facilities NO. NGC-1

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Modified Aircraft Navigation Gear

TEST DESCRIPTION: Range of altitudes ALT. (max/min) 500 / 300 km, INCL. ______ deg, TIME (continuous automatic) hr

BENEFIT OF SPACE TEST: Potential cost reduction of mission support

EQUIPMENT: WEIGHT 100 kg, SIZE ? X ? X ? m, POWER .1 kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION Earth CREW. NO. ______ OPERATIONS/DURATION /

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: This device exists for aircraft flights in an operational mode; no further tests other than preparation for shuttle is needed.

TEST DESCRIPTION/REQUIREMENTS: ______

SPECIAL GROUND FACILITIES: ______

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ______

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-2
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Guidance, Navigation & Control

2. TITLE Scanning Laser Radar (SLR)

3. TECHNOLOGY ADVANCEMENT REQUIRED

Completion and refinement of design and construction, development test and flight qualification of the SLR

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
5	6	7

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1983
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Potential high reliability, low power, no moving parts, and as a system will provide a means of autonomous rendezvous and docking.

POTENTIAL COST BENEFITS Simpler mechanism than conventional radar indicates potential cost savings of $150,000 per system.

ESTIMATED COST SAVINGS $ 1.5 million

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Determining the optimum Laser material and refinement of the system concept for accurate ranging at close range.

REQUIRED SUPPORTING TECHNOLOGIES Continued research of Laser materials and improvement in the signal processing.

7. REFERENCE DOCUMENTS/COMMENTS RTOP 909-55-10.

FT/TDR 10/7/75

TITLE Scanning Lazer Radar (SLR) NO. NGC-2

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: One SLR with suitable free flying vehicle for transporting system and a target for demonstrating the rendezvous and closing ability and accuracy.

TEST DESCRIPTION: ALT. (max/min) 100 / ____ km, INCL. Any deg, TIME 25 hr

Target vehicle to rendezvous, station keeping and docking.

BENEFIT OF SPACE TEST: Demonstrates performance of a complex system in its working environment.

EQUIPMENT: WEIGHT 10 kg, SIZE .2 X .2 X .3 m, POWER .3 kW

POINTING Free Flyer/EOTS STABILITY N/A DATA ____

ORIENTATION ____ CREW: NO. 1 OPERATIONS/DURATION 2 /2hrs/omh

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 95%

9. GROUND TEST OPTION TEST ARTICLE: SLR and target.

TEST DESCRIPTION/REQUIREMENTS: SLR and/or target for maneuvering, demonstrating and testing accuracy of system.

SPECIAL GROUND FACILITIES: Six degree-of-freedom mobility unit in a large test area for simulation and accuracy demonstrations.

EXISTING: YES ☐ NO ☒

GROUND TEST LIMITATIONS: Limited freedom of translation

TEST CONFIDENCE 75%

10. SCHEDULE & COST

TASK	CY	Space 75	76	77	78	79	80	COST ($)	Ground 75	76	77	78	79	80	COST ($)
1 ANALYSIS		---	----					.1m	---	---					.1m
2. DESIGN		---	----	---				.4m	--	----	---				.4m
3 MFG & C/O			---	----	---			2.0m							[illegible].0m
4 TEST & EVAL								.5m							1.5m
TECH NEED DATE															
		GRAND TOTAL						3.0m	GRAND TOTAL						4.0m

11. VALUE OF SPACE TEST $ Billions (SUM OF PROGRAM COSTS $ 3M)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-3
PAGE 1

1. REF. NO. ______ PREP DATE 8/8/75 REV DATE ______ LTR ______
CATEGORY Guidance Navigation and Control

2. TITLE Stray Light Rejection Testing

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

It is extremely difficult and expensive to evaluate stray light attenuators (sun & earth shades) in earth based facilities. One reason is that test facility walls scatter light from the solar simulators. This makes verification of new designs difficult. Shuttle sortie flights provide an opportunity to evaluate the attenuation qualities of new sun shade designs and to provide verification of design equations and procedures.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1982
PAYLOAD DEVELOPMENT LEAD TIME 2 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS various

TECHNICAL BENEFITS Positive proof of design adequacy with resultant minimization of design and evaluation costs. It would still be necessary to evaluate individual members of a design family to insure quality control (i.e., nicks and dents); however, this is a much simpler task.

POTENTIAL COST BENEFITS This procedure eliminates the need to design, build and maintain a precise test facility as proposed by the STS advanced systems technology guidance and control working group.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS None-Shuttle/space lab capabilities

REQUIRED SUPPORTING TECHNOLOGIES Space lab compatible

7. REFERENCE DOCUMENTS/COMMENTS "STS Advanced Systems Technology Guidance and Control Working Group", Jan 1974; also DOTR number 11, "Stray Light Rejection".

FT (TDR 1) 7/75

TITLE Stray Light Rejection Testing

NO. NGC-3

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Sun and Earth Shades

TEST DESCRIPTION: ALT (max/min) -- / ____ km, INCL. Any deg, TIME 2 hr

BENEFIT OF SPACE TEST:

EQUIPMENT: WEIGHT various kg, SIZE various X ____ X ____ m, POWER .01 kW

POINTING one degree STABILITY shuttle comparability DATA photomultiplier

ORIENTATION relative to sun/earth CREW NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: None beyond existing

EXISTING: YES ☐ NO ☒

TEST CONFIDENCE high

9. GROUND TEST OPTION TEST ARTICLE: Sun Shade

TEST DESCRIPTION/REQUIREMENTS:

SPECIAL GROUND FACILITIES: New facility required

EXISTING: YES ☐ NO ☒

GROUND TEST LIMITATIONS:

TEST CONFIDENCE medium

10. SCHEDULE & COST

TASK	CY	Space Test Option						COST ($)	Ground Test Option						COST ($)
1. ANALYSIS															
2. DESIGN															
3 MFG & C/O															
4 TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FUTURE PAYLOAD TECHNOLOGY — NO. NGC-4

TESTING AND DEVELOPMENT REQUIREMENT — PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______

CATEGORY Guidance, Navigation & Control

2. TITLE Low-g accelerometer testing

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Low-g accelerometers capable of measuring accelerations as low as 10^{-8} M/S^2 and lower are required for Earth and Ocean Physics Missions for measurement of the influence of drag on gravity study satellites. Many of the problems associated with development of instruments of this type relate to the ability to introduce very low accelerations. A zero-g environment provides a solution to many of the problems encountered in earth measurements.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1985

PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1982

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS The principal benefit in providing a zero-g space environment to testing of low-g accelerometers is elimination of elaborate seismic isolation techniques and sophisticated measurement equipment. Lower "g" measurement instrument capability (10^{-8} M/S^2) will enable new mission technology.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Isolation of accelerometer from shuttle disturbances requires a floating test bed with associated instrumentation support functions.

REQUIRED SUPPORTING TECHNOLOGIES Instrumentation, data processing, communication

7. REFERENCE DOCUMENTS/COMMENTS NGC-14

FT-TDR 1/7/75

TITLE Low-g Accelerometer Testing

NO. NGC-4

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: 10^{-8} M/S^2 Accelerometer and Associated Floating Test Bench

TEST DESCRIPTION: ALT. (max/min) no limit / ____ km, INCL. any deg, TIME 1 hr

BENEFIT OF SPACE TEST. Only way to test low-g accelerometers ----- impossible on ground.

EQUIPMENT: WEIGHT 150 kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING any STABILITY 1°RMS DATA ____

ORIENTATION any CREW: NO. ____ OPERATIONS/DURATION 12 / 1/2 HR

SPECIAL GROUND FACILITIES: ____

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: Impractical to test on ground

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS. ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION 76	77	78	79	80	81	COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS		—	—												
2. DESIGN			—	—											
3 MFG & C/O					—	—									
4. TEST & EVAL						—									
TECH NEED DATE							Δ								
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

LI(TDR 29 7 75

FUTURE PAYLOAD TECHNOLOGY NO. NGC-5

TESTING AND DEVELOPMENT REQUIREMENT PAGE 1

1. REF. NO. ______ PREP DATE 8/8/75 REV DATE ______ LTR ______

CATEGORY Guidance, Navigation and Control

2. TITLE Redundant Strapdown Laser Inertial Measurement Unit for Space Missions

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Completion of contruction, development test and flight qualification of the redundant strapdown Inertia Measurement Unit (IMU). Gyro itself has been flight tested.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1983

PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Potential high reliability low power wide dynamic range, insensitive to gravity; fewer navigation computations.

POTENTIAL COST BENEFITS Simpler mechanism than conventional gyros indicates potential cost savings of $150,000 per system.

ESTIMATED COST SAVINGS $ 1.5 million

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Developing reliable electronics

REQUIRED SUPPORTING TECHNOLOGIES RTOP's 506-29-11 909-55-10

NGC-14

7. REFERENCE DOCUMENTS/COMMENTS

FT (TDR 1) 7/75

TITLE Redundant Strapdown Laser IMU for Space Missions NO. NGC-5

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: One IMU with suitable docking target vehicle and remote manipulator to carry IMU. Uses SUMC Processor

TEST DESCRIPTION: ALT (max/min) 100 / --- km, INCL. Any deg, TIME 25 hr

Target vehicle station--helps to provide rendezvous and docking for IMU

BENEFIT OF SPACE TEST: Demonstrates performance of a complex sensor in its working environment

EQUIPMENT. WEIGHT 10 kg, SIZE .25 X .25 X .25 m, POWER .300 kW

POINTING remote manipulator STABILITY N.A. DATA

ORIENTATION CREW NO. 1 OPERATIONS/DURATION 2 / 2 hrs./omh

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE 95%

9. GROUND TEST OPTION TEST ARTICLE: IMU and target

TEST DESCRIPTION/REQUIREMENTS: IMU and/or target are manipulated (maneuvered) to simulate docking orientation

SPECIAL GROUND FACILITIES: Six degree of freedom mobility unit or manipulator in a chamber large enough to simulate docking

EXISTING: YES ☐ NO ☒

GROUND TEST LIMITATIONS: No sunlight, limited freedom of translation and perhaps no vacuum, Ground Test van & helicopter.

TEST CONFIDENCE 75%

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION 75	76	77	78	79	80	COST ($)	GROUND TEST OPTION 75	76	77	78	79	80	COST ($)
1. ANALYSIS								.1M							.1M
2. DESIGN								.4M							.4M
3 MFG & C/O								2.0M							2.0M
4 TEST & EVAL								.5M							1.5M
TECH NEED DATE				X								X			
GRAND TOTAL								3.0M							4.0M

11. VALUE OF SPACE TEST $ billions (SUM OF PROGRAM COSTS $ 3M)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-6
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Guidance, Navigation and Control

2. TITLE Optical Correlator Landmark Tracker

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

To develop a landmark tracker capable of pointing to an arbitrarily selected landmark for earth oriented satellites. Such a sensor will provide pointing signals for these instruments similar to that provided to inertially stabilized instruments by guided star sensors, i.e., it will make the earth a cooperative target.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1981
PAYLOAD DEVELOPMENT LEAD TIME 5 YEARS. TECHNOLOGY NEED DATE 1976

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Arbitrary earth pointing capability without precise attitude determination of orbital parameter knowledge; instrument pointing independent of mapping errors; real-time matching of targets rather than post-flight.

POTENTIAL COST BENEFITS Significant reduction in ground based mission support, reduction in data transmission requirements since specific locations can be viewed and examined

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Refinement of optically excited liquid crystals for higher resolution. Search procedures to identify landmark techniques to elimi ate moving parts.

REQUIRED SUPPORTING TECHNOLOGIES Optically excited liquid crystals

7. REFERENCE DOCUMENTS/COMMENTS DOTR Number 19

FT/TDR 11/7/75

TITLE Optical Correlator Landmark Tracker

NO. NGC-6
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Landmark Tracker

TEST DESCRIPTION: ALT. (max/min) 500 / 200 km, INCL. any deg, TIME 4 hr

BENEFIT OF SPACE TEST. Verify feasibility and system insensitivity to variations in lighting; orbital parameters; and cloud cover

EQUIPMENT: WEIGHT ____ kg, SIZE 1.1 X .5 X .5 m, POWER ____ kW

POINTING 1st FLT-.5°laser/sec STABILITY ____ DATA ____

ORIENTATION Earth oriented CREW: NO. 1 OPERATIONS/DURATION 10 / 4

SPECIAL GROUND FACILITIES: No known special facilities

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE high

9. GROUND TEST OPTION TEST ARTICLE: Landmark Tracker

TEST DESCRIPTION/REQUIREMENTS: Using various photographs of earth, targets taken under different conditions, check correlation

SPECIAL GROUND FACILITIES: None

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS: Limited target variation

TEST CONFIDENCE fair

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-7
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Guidance, Navigation and Control

2. TITLE Video Correlator Landmark Tracker

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
4	4	7

To develop a landmark tracker capable of pointing to an arbitrarily selected landmark for earth oriented satellites. Such a sensor will provide pointing signals for these instruments similar to that provided to inertially stabilized instruments by guide star sensors, i.e., it will make the earth a cooperative target. The video and optical landmark tracker are two alternate techniques for doing the same task.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1981
PAYLOAD DEVELOPMENT LEAD TIME 5 YEARS. TECHNOLOGY NEED DATE 1976

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______
TECHNICAL BENEFITS Same as optical correlator landmark tracker

POTENTIAL COST BENEFITS Same as optical correlator landmark tracker

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS The technical problems are significantly different from the optical correlator landmark tracker. Principally the development of software to allow individual targets to be reacquired.

REQUIRED SUPPORTING TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR 1) 7 75

TITLE Video Correlator Landmark Tracker

NO. NGC-7

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Video Correlator Landmark Tracker

TEST DESCRIPTION: ALT (max/min) 500 / 200 km, INCL. any deg, TIME 4 hr

BENEFIT OF SPACE TEST: verify feasibility and system capabilities

EQUIPMENT: WEIGHT ____ kg, SIZE 1.1 X .5 X .5 m, POWER ____ kW

POINTING 1st FLT-.5°;later 1sec STABILITY ____ DATA ____

ORIENTATION Earth CREW NO. 1 OPERATIONS/DURATION 10 / 4

SPECIAL GROUND FACILITIES: No known special ground facilities

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE high

9. GROUND TEST OPTION TEST ARTICLE. ____

TEST DESCRIPTION/REQUIREMENTS: Simulate earth as seen from space

SPECIAL GROUND FACILITIES: None

EXISTING. YES [X] NO [ ]

GROUND TEST LIMITATIONS. ____

TEST CONFIDENCE fair

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4 TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FF(TDR 20 7 75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-8
PAGE 1

1. REF. NO. ____ PREP DATE ____ REV DATE ____ LTR ____
CATEGORY Guidance, Navigation and Control

2. TITLE Video Inertial Pointing System for Shuttle Astronomy Payloads

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	5	7

Pointing at non-visible or dim astronomy objects is crucial to astronomy missions and requires tracking stars of the adjacent star field. Since the position of many dim targets is not precisely known with respect to the star field, the ability to view the adjacent field and complete the acquisition with an operator is required. A video sensor can provide three-axis error signals for gyro drift correction and a CRT display for human interaction.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1983
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ____

TECHNICAL BENEFITS 1. Increase in the number of faint astronomy sources that can be observed. 2. Increased system operational flexibility due to field display. 3. Increased system reliability due to decrease in number of star trackers. 4. Increased system accuracy due to multi-star processing and error averaging.

POTENTIAL COST BENEFITS 1. Increased mission output for given on orbit time. 2. Reduced number of conventional startrackers. 3. Lower performance gyros.

ESTIMATED COST SAVINGS $ ____

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS 1. Development of video sensor with adequate sensitivity and resolution. 2. Development of multi-star processing equations. 3. Development of optimum gyro filters. 4. Development of guide star selection and manual control algorithms.

REQUIRED SUPPORTING TECHNOLOGIES CCD Detector Improvements

7. REFERENCE DOCUMENTS/COMMENTS 1. RTOP 506-19-15 "Video Inertial Pointing Pointing System Shuttle Astronomy Payloads"
2. RTOP 506-19-14 "Extended Life Attitude Control System for Unmanned Planetary Vehicles"

FT (TDR 1) 7/75

TITLE Video Inertial Pointing System for Shuttle Astronomy Payloads NO. NGC-8

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Prototype Video Inertial Pointing System

TEST DESCRIPTION: ALT. (max/min) 600 / 300 km, INCL. ______ deg, TIME 24 hr

Track celestial targets and obtain actual astronomy data using system

BENEFIT OF SPACE TEST: Performance tests of video sensor and system software; operational system demonstration

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION 24 /1.5 hrs.

SPECIAL GROUND FACILITIES: Video sensor calibration laboratory

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE .85

9. GROUND TEST OPTION TEST ARTICLE: Prototype Video Inertial Pointing

TEST DESCRIPTION/REQUIREMENTS: balloon aircraft tests

SPECIAL GROUND FACILITIES: Gimbal stabilization system

EXISTING: YES [X] NO [ ]

GROUND TEST LIMITATIONS: Atmospheric effects limit tracking point sources.

TEST CONFIDENCE .6

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ 73m (SUM OF PROGRAM COSTS $ 300m)

12. DOMINANT RISK/TECH PROBLEM

	COST IMPACT	PROBABILITY
Resolution and sensitivity	.02	0.3
Requirement on CCD video sensor		

COST RISK $ 0.06

SI (TDR 2/7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-9
PAGE 1

1. REF. NO. ________ PREP DATE 8/8/75 REV DATE ________ LTR ____
CATEGORY Guidance, Navigation and Control

2. TITLE Attitude Control of a Flexible Structure

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	5	7

Instrument pointing from a flexible structure, typical of manned, earth resource, and planetary spacecraft of the future, need control systems capable of filtering the motions caused by the flexibility of the main spacecraft. On-going work (RTOP 506-19-14) will develop the tools for incorporating a realistic nonrigid vehicle model into the design of a stochastic controller by 1979. A non-flight critical control system, preferably programmable, designed with control algorithms based on dynanical models of the supporting structure, would provide a practical demonstration of the new analytical tools.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1983
PAYLOAD DEVELOPMENT LEAD TIME 2 YEARS. TECHNOLOGY NEED DATE 1981

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ________

TECHNICAL BENEFITS The principal benefit of the technology advancement is improved pointing capability for instruments and improved attitude and stability of experiments and systems. The benefit of the experiment is to provide actual control system demonstration, prior to mission dependence, of the analytical tools. A comparable demonstration in a one-g field is virtually impossible.

POTENTIAL COST BENEFITS To achieve improved mission success of attitude and/or stability, dependent experiments and systems. This could run into the 100's of millions of dollars.

ESTIMATED COST SAVINGS $ 20 million

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS proper instrumentation

REQUIRED SUPPORTING TECHNOLOGIES high accuracy angular rate sensors desirable

7. REFERENCE DOCUMENTS/COMMENTS See DTR #25 and RTOP 506-19-14.

FT (TDR 1) 7 75

TITLE Attitude Control of a Flexible Structure NO. NGC-9

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Large Flexible Structures

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Evaluate pointing and stability at orbit--could be in conjunction with test and evaluation of figure control

BENEFIT OF SPACE TEST: Test and evaluate full scale system and verify design procedures for follow-on missions.

EQUIPMENT: WEIGHT 1000-2000 kg, SIZE 10-100 meter diameter X ____ X ____ m, POWER 1 kW

POINTING one to five arc sec STABILITY .1 sec/sec DATA ____

ORIENTATION various CREW: NO. 1 OPERATIONS/DURATION ____ / 2 days

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: Only component and subsystem level tests can be performed on the ground.

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3 MFG & C/O															
4 TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-10
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Guidance, Navigation and Control

2. TITLE Figure Control of Large Deformable Structures

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	3	7

Large precision structures (typically large antennas for high resolution earth observations; astronomy interferome .ers, etc.) cannot be maintained in space without active control of their surface shape. Orders of magnitude loss of resolution can result from uncontrolled deformation of antennas.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1983
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS By achieving maximum benefit from each system improved data and reduced data rate can be achieved.

POTENTIAL COST BENEFITS Reduction in number of satellite missions and increase in data quality resulting in 100's of million of dollars in benefits.

ESTIMATED COST SAVINGS $ 20 million

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Types and location of activators to be used
Structural modeling and fabrication methods
Sensors for measuring structural deformation to the requisite accuracy
New approaches to the coupling and control of modular array elements

REQUIRED SUPPORTING TECHNOLOGIES NASA TND-7090; NASA CR-2073 DOTR #26 "shape control of large deformable structures", DOTR #40 Magnetic large array assembly and shape management.

7. REFERENCE DOCUMENTS/COMMENTS

FT 1081 7/76

TITLE Figure Control of Large Deformable Structures

NO. NGC-10

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION

TEST ARTICLE: Large, lightweight, structure, and modular arrays

TEST DESCRIPTION: ALT. (max/min) 500 / 200 km, INCL Any deg, TIME 2 days hr

(1) Transport and unfurl a large light-weight structure in space to evaluate surface control (should use structure for future on-going mission)

(2) Deploy small set of magnetically coupled modular arrays linked to shuttle or freeflying body.

BENEFIT OF SPACE TEST: Evaluate concert and engineering evaluation of on-going system.

EQUIPMENT: WEIGHT 1000-2000 kg, SIZE ____ X between 10&100 meter diameter X ____ m, POWER one (1) kW

POINTING TBD STABILITY TBD DATA ____

ORIENTATION various CREW NO. 1 OPERATIONS/DURATION 10 / 2 days

SPECIAL GROUND FACILITIES: construction and assembly

EXISTING: YES [?] NO [ ]

TEST CONFIDENCE high

9. GROUND TEST OPTION

TEST ARTICLE: There is probably no good ground test option available since the structures cannot support their own weight.

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING YES [ ] NO [ ]

GROUND TEST LIMITATIONS. ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1 ANALYSIS															
2 DESIGN															
3 MFG & C/O															
4 TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-11
PAGE 1

1. REF. NO. ______ PREP DATE 6/8/75 REV DATE ______ LTR ____
CATEGORY Guidance, Navigation and Control

2. TITLE Teleoperator Orbiter Bay Experiment (TOBE)

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	7	7

This experiment will consist of a vehicle of modular design containing manipulator(s) and visual sensors operated remotely in the orbiter bay. The system will provide proof demonstration and crew familiarization in the space environment. This will also be a precursor to the Earth Orbital Teleoperator Experiment Demonstration Flight.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1981
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1978

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Demonstrate man-machine capability in space for hardware manipulation and servicing. In some cases man without teleoperator support, would be unable to carry out the required tasks.

POTENTIAL COST BENEFITS Greatly reduced time to carry out certain tasks. The integration of this time saving would ultimately save an extra shuttle flight.

ESTIMATED COST SAVINGS $ 10 million per flight saved.

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Technical problems, which are currently being pursued, include: manipulator design, manipulator sensors, data display, interaction of operator with control and data display hardware and computer applications.

REQUIRED SUPPORTING TECHNOLOGIES T.V. imaging, computers, optical and mechanical sensors.

7. REFERENCE DOCUMENTS/COMMENTS See DTR #36 and RTOP 970-63-20 "Technology for Remote Manned Control for Payload Servicing."

FT-TDR 1/7/75

TITLE Telcoperator Orbiter Bay Experiment (TOBE) NO. NGC-11

COMPARISON OF SPACE & GROUND TEST OPTIONS

SPACE TEST OPTION TEST ARTICLE: TOBE would be a modular structure consisting of manipulators, docking adapter, visual & R.F. system plus a task board for demonstrating the dexterity required for conducting a variety of manipulative tasks in zero gravity.

TEST DESCRIPTION: ALT (max/min) N/A / N/A km, INCL N/A deg, TIME 6ea.-1 hr

This experiment will be conducted in the Orbiter Bay under varying lighting conditions as provided by both day and night cycles of orbit.

BENEFIT OF SPACE TEST. Less costly to demonstrate in the zero-gravity environment of space than to simulate the same on earth.

EQUIPMENT: WEIGHT 185 kg, SIZE 1 X 1 X 1.5 m, POWER .75 kW

POINTING N/A STABILITY N/A DATA Video/power/recordings

ORIENTATION N/A CREW NO. 1 OPERATIONS/DURATION 6 / 1 hr.

SPECIAL GROUND FACILITIES: Video monitor and telemetry of power measurements would be desirable. EXISTING: YES [?] NO [ ]

TEST CONFIDENCE 100

9. GROUND TEST OPTION TEST ARTICLE: The TOBE would be tested as a proto-flight system limited to one-g environment.

TEST DESCRIPTION/REQUIREMENTS: Perform limited manipulative task in one-g remotely aided by video systems.

SPECIAL GROUND FACILITIES: The teleoperator manipulator and mobility unit test facility (EOTS simulator) located at MSFC.

EXISTING: YES [X] NO [ ]

GROUND TEST LIMITATIONS: Limited to one-g conditions, no vacuum and unreal thermal control.

TEST CONFIDENCE 50

10. SCHEDULE & COST

TASK	CY	Space 76	77	78	79	80	81	COST ($)	Ground 76	77	78	79	80	81	COST ($)
1. ANALYSIS		--						.1	--						.1
2. DESIGN			----	--				.5M		---	--				.5M
3. MFG & C/O				---	----			2.5M		----	---				3.0M
4. TEST & EVAL						----		.4M					---		1.0M
TECH NEED DATE							X							X	
		GRAND TOTAL						3.5M	GRAND TOTAL						4.6M

11. VALUE OF SPACE TEST $ Billions (SUM OF PROGRAM COSTS $ 4 Million)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $

TITLE Teleoperator Orbiter Bay Experiment (TOBE) NO. NGC-11

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

SPACE TEST OPTION TEST ARTICLE: TOBE would be a modular structure consisting of manipulators, docking adapter, visual & R.F. system plus a task board for demonstrating the dexterity required for conducting a variety of manipulative tasks in zero gravity.

TEST DESCRIPTION: ALT (max/min) N/A / N/A km, INCL N/A deg, TIME 6ea.-1 hr

This experiment will be conducted in the Orbiter Bay under varying lighting conditions as provided by both day and night cycles of orbit.

BENEFIT OF SPACE TEST Less costly to demonstrate in the zero-gravity environment of space than to simulate the same on earth.

EQUIPMENT: WEIGHT 185 kg, SIZE 1 X 1 X 1.5 m, POWER .75 kW

POINTING N/A STABILITY N/A DATA Video/power/recordings

ORIENTATION N/A CREW NO. 1 OPERATIONS/DURATION 6 / 1 hr.

SPECIAL GROUND FACILITIES: Video monitor and telemetry of power measurements would be desirable. EXISTING: YES [?] NO [ ]

TEST CONFIDENCE 100

9. **GROUND TEST OPTION** TEST ARTICLE: The TOBE would be tested as a proto-flight system limited to one-g environment.

TEST DESCRIPTION/REQUIREMENTS: Perform limited manipulative task in one-g remotely aided by video systems.

SPECIAL GROUND FACILITIES: The teleoperator manipulator and mobility unit test facility (EOTS simulator) located at MSFC.

EXISTING: YES [X] NO [ ]

GROUND TEST LIMITATIONS: Limited to one-g conditions, no vacuum and unreal thermal control.

TEST CONFIDENCE 50

10. **SCHEDULE & COST**

TASK		SPACE TEST OPTION							GROUND TEST OPTION						
	CY	76	77	78	79	80	81	COST ($)	76	77	78	79	80	81	COST ($)
1. ANALYSIS		--						.1	--						.1
2. DESIGN			----	-				.5M		----	-				.5M
3. MFG & C/O				---	---			2.5M		----	--				3.0M
4 TEST & EVAL						----		.4M					---		1.0M
TECH NEED DATE							X							X	
		GRAND TOTAL						3.5M	GRAND TOTAL						4.6M

11. VALUE OF SPACE TEST $ Billions (SUM OF PROGRAM COSTS $ 4 Million)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $

MSFC-DP 20 7 75

REPRODUCIBILITY OF THE

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-12
PAGE 1

1. REF. NO. ________ PREP DATE 8/8/75 REV DATE ________ LTR ____
CATEGORY Guidance, Navigation and Control

2. TITLE Earth Orbital Teleoperator System (EOTS)

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	7	7

This experiment will be a "free flyer" experiment which will contain the Teleoperator Orbiter Bay Experiment (TOBE) type components and systems--manipulators, docking adapters, visual system, RF systems plus the guidance and propulsion systems.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1983
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ________
TECHNICAL BENEFITS The flight experiment will demonstrate the ability for deploying, rendezvousing, retrieving, inspecting, servicing and assembling payloads and satellites.

POTENTIAL COST BENEFITS Will enable the repair and servicing of satellites which would otherwise have to be abandoned or returned to Earth for more expensive servicing.

ESTIMATED COST SAVINGS $ 100 Million

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS Technical problems, which are currently being pursued, include: manipulator design, manipulator sensors, data display, interaction of operator with control and data display hardware and computer applications.

REQUIRED SUPPORTING TECHNOLOGIES T. V. imaging, antennas, guidance and navigation, computers, optical and mechanical sensors.

7. REFERENCE DOCUMENTS/COMMENTS See DTR #36 and RTOP 970-63-20 "Technology for Remote Manned Control for Payload Servicing."

FT/TDR 11/7/75

FUTURE PAYLOAD TECHNOLOGY — NO. NGC-13

TESTING AND DEVELOPMENT REQUIREMENT — PAGE 1

1\. REF. NO. ______ PREP DATE 8/12/75 REV DATE ______ LTR ____

CATEGORY Guidance, Navigation and Control

2\. TITLE Modular Instrument Pointing Technology Laboratory (MIPTL)

3\. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

In addition to precision pointing system technology, there are a number of guidance and control pointing elements and systems for both earth viewing and astronomy that form the elements of a Shuttle Spacelab experiment. Such a laboratory would be required to provide position control to <10 sec and be designed for changeout of pointing instruments and various elements of the pointing control system.

4\. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1980-1981

PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1980

5\. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS Many

TECHNICAL BENEFITS The benefits of an instrument pointing technology laboratory with an initial accuracy on the order of a few arc-seconds would be the opportunity of testing various sensors and elements of pointing systems in an earth orbital application at a relatively low cost. The laboratory would be reconfigurable and serve a continuous test capability for pointing and control technology.

POTENTIAL COST BENEFITS

ESTIMATED COST SAVINGS $

6\. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS The principal problem in designing an instrument pointing technology laboratory is the sophistication of the modular concept. To be cost effective as a testing tool the laboratory would have to allow various components to be tested and instrumented without major impact or redesign of laboratory elements.

REQUIRED SUPPORTING TECHNOLOGIES

1. Platform isolation system
2. Attitude determination and relative instrumentation

7\. REFERENCE DOCUMENTS/COMMENTS Applicable on-going programs might include 506-19-13 Advanced s/c and control systems and 506-19-14 Extended Life A/C Systems and 506-19-15 Video Inertial Pointing

FT (TDR-1) 7/75

TITLE Modular Instrument Pointing Technology Laboratory (MIPTL) NO. NGC-13

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: ____________

TEST DESCRIPTION : ALT. (max/min) ______ / ______ km, INCL. ______ deg, TIME ______ hr

BENEFIT OF SPACE TEST: ____________

EQUIPMENT: WEIGHT ______ kg, SIZE ______ X ______ X ______ m, POWER ______ kW

POINTING ______ STABILITY ______ DATA ______

ORIENTATION ______ CREW: NO. ______ OPERATIONS/DURATION ______ / ______

SPECIAL GROUND FACILITIES: ____________

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ______

9. GROUND TEST OPTION TEST ARTICLE: ____________

TEST DESCRIPTION/REQUIREMENTS: ____________

SPECIAL GROUND FACILITIES: ____________

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____________

TEST CONFIDENCE ______

10. SCHEDULE & COST

TASK	SPACE TEST OPTION							GROUND TEST OPTION						
CY							COST ($)							COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ______ (SUM OF PROGRAM COSTS $ ______)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ______

LTDR 2/7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-14
PAGE 1

1. REF. NO. ______ PREP DATE 8/13/75 REV DATE ______ LTR ______
CATEGORY Navigation, Guidance and Control

2. TITLE Inertial Components Flight Test Facility

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
2	5	7

This facility (module) is viewed as a device to evaluate advanced navigation components and would be used over a period of many years. This facility is essentially a "free flyer" on board the shuttle (spacelab). This module would be released from shuttle (to isolate disturbances) and inertially stabilized. The shuttle is flown so as to "station keep" with the module. Within this facility it would be possible to evaluate a variety of components such as low-g accelerometers, gyroscopic components, and inertial measurement units.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1985
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1982

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______
TECHNICAL BENEFITS Obtaining very low-g capability of providing isolation for precision stability measurements is extremely difficult on earth. The present state-of-the-art can be refined, but order(s) of magnitude improvements can be obtained only in space.

POTENTIAL COST BENEFITS Alternate earth based facilities are either impossible to build or at best extremely expensive.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT
TECHNICAL PROBLEMS The technology to build and operate the proposed facility is generally available. The free flyer will be similar in complexity to a present-day sounding rocket payload.

REQUIRED SUPPORTING TECHNOLOGIES NGC-4; NGC-5

7 REFERENCE DOCUMENTS/COMMENTS

FT-TDR 11/7/75

TITLE Inertial Components Flight Test Facility NO. NGC-14

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Inertial Components

TEST DESCRIPTION: ALT. (max/min) Any / km, INCL. Any deg, TIME 8 hr

Components are mounted on the free flyer and allowed to "float" while output is monitored.

BENEFIT OF SPACE TEST: Evaluation of components *in situ* and under conditions (isolation) unobtainable in space

EQUIPMENT: WEIGHT 1000 kg, SIZE 2 X 1 X 1 m, POWER 2 kW

POINTING provided by facility STABILITY provided by facility DATA

ORIENTATION Inertial CREW: NO. 1 OPERATIONS/DURATION 2 / 4

SPECIAL GROUND FACILITIES: Component alignment and functional test

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE .95

9. GROUND TEST OPTION TEST ARTICLE: Inertial Components

TEST DESCRIPTION/REQUIREMENTS: The present state-of-the-art probably cannot be extended by the orders of magnitude that can be achievable in space.

SPECIAL GROUND FACILITIES:

EXISTING: YES [ ] NO [X]

GROUND TEST LIMITATIONS: Disturbances from seismic forces, tidal forces, and the inability to align with the earth's gravitational field.

TEST CONFIDENCE

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION 76	77	78	79	80	81	COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS			—												
2. DESIGN				—	—										
3. MFG & C/O					—	—									
4. TEST & EVAL						—	—								
TECH NEED DATE							Δ								
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ (SUM OF PROGRAM COSTS $)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $

FUTURE PAYLOAD TECHNOLOGY

TESTING AND DEVELOPMENT REQUIREMENT

NO. NGC-15

PAGE 1

1. REF. NO. ____ PREP DATE ____ REV DATE ____ LTR ____

CATEGORY Guidance, navigation and control

2. TITLE Free Flying Interferometer

3. TECHNOLOGY ADVANCEMENT REQUIRED

Demonstration of free-flying long base-line interferometer of sufficient gain and accuracy to be used with small ground beacons and antennas and weak stellar sources.

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1985

PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1982

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ____

TECHNICAL BENEFITS Such interferometers can be used as a basis for creating navigation and control and search and rescue systems for mobile earth platforms such as ships and aircraft.

POTENTIAL COST BENEFITS Could be instrumental in eliminating ship collisions and search and rescue position location.

ESTIMATED COST SAVINGS $ 2 Billion/yr.

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS Obtaining sufficient signal gain and accuracy.

REQUIRED SUPPORTING TECHNOLOGIES Ground beacons.

7. REFERENCE DOCUMENTS/COMMENTS Outlook for Space Objective 034 - Communication - Navigation and DOTR 38.

FT (TDR 1) 7 75

TITLE Free Flying Interferometer

NO. NGC-15

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Free-flyer and shuttle based interferometer equipment

TEST DESCRIPTION: ALT (max/min) 500 / 300 km, INCL. ____ deg, TIME 2 hr

BENEFIT OF SPACE TEST. Provide a basis for a navigation, control, and search and rescue system for mobile land platform.

EQUIPMENT: WEIGHT 1000 kg, SIZE 3 X 3 X 3 m, POWER 1 kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION Earth CREW NO. ____ OPERATIONS/DURATION 10 / 1 hr.

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☒

TEST CONFIDENCE .95

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS. ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS. Virtually impossible to duplicate on ground.

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3 MFG & C/O															
4 TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

IV. SHUTTLE PAYLOADS

A. INTRODUCTION

In Section II, User Requirements were grouped under the three major thrusts that were developed as logical summary goals for Navigation, Guidance and Control.

The Technology Requirements that were subsequently generated (Section III) were also grouped under these major thrusts. In a similar manner, the recommended flight experiments developed from the Technology Requirements and discussed in this section can also be organized under these major thrusts.

This organization of experiments is shown in Table I. As can be seen, each major thrust has produced several shuttle experiments. In some cases, a number of individual experiments have been grouped to result in what appears to be an efficient payload--a payload that will minimize development costs and possibly the number of flights.

The total group of experiments, each including a brief description, a justification for the experiment, references to the Technology Descriptions and the Payload Technology Forms is presented in the following material.

B. GROUPING OF EXPERIMENTS

Forty-seven technology requirements were identified that support the user requirements. From these, a total of 15 were identified that could benefit from a space test. Some of the future payload technology space tests require or are enhanced by the space environment, while others benefit from a systems test, required for user acceptance, that can only be performed meaningfully in space.

Several of the payload technology space tests fit into groups that could use similar support facilities on the shuttle. Two of these classes are listed below with their proposed experiments:

1. Inertial Components Test Facility
   a. Low-g accelerometer tests
   b. Redundant strapdown IMU for space missions
2. Modular Instrument Pointing Test Facility
   a. Optical correlator landmark tracker
   b. Video correlator landmark tracker
   c. Video Inertial Pointing System for Shuttle Astronomy Payloads

These two test facilities are characterized by having the potential to support technology development over an extended period of time of a broad class of NASA uses or mission requirements.

C. EXPERIMENTS AND RATIONALE

All of the shuttle experiments that have been identified from the technology requirements can be categorized according to whether the experiment supports mission driven or opportunity driven technology. Mission driven refers to technology requirements that have been identified or are related to future missions. Opportunity driven refers to technology requirements that would provide new enabling technology for potential missions that have not yet been identified. Table II shows each proposed experiment, its basis for justification and whether it is opportunity driven or mission driven.

Table III correlates the Outlook for Space, User Inputs, Major Thrusts, and the majority of the technology requirements. The first three sections of this table will allow the reader to determine the specific technology related to the other three areas. The next section of the table enumerates a specific user requirement and technology response outside the major thrust. The final section identifies those areas which form a part of any consistent continuing program: the necessary effort to refine the state-of-the-art so that maximum benefits can be achieved. Also grouped in this area are those DOTR's which were referred to other working groups. The numbers in front of the technology items provide a quick reference to the DOTR's which will provide more detailed information on the specific technology. In this table each technology item appears only once opposite that set of areas to which it most logically applies. In general, the OFS and User Inputs have been grouped according to similar functions which allow adjacent vertical areas across the chart to be associated together. However, many of the technology items apply to a number of other areas. Table III-A shows this cross-correlation but requires that the reader refer to Table III and the index to determine the items being correlated.

The following pages present brief resumes of each experiment, and this is followed directly by considerable detail in the form of the "Future Payload Technology Testing and Development Requirement" Forms.

<u>Major Thrust</u> REDUCE MISSION SUPPORT COST BY 50% THROUGH AUTONOMOUS OPERATION BY 1990

<u>Experiments</u>: 1. Low Cost Navigation Independent of NASA Tracking Facilities

2. Scanning Laser Radar (SLR)

<u>Major Thrust</u> PROVIDE A TEN-FOLD INCREASE IN MISSION OUTPUT THROUGH IMPROVED POINTING AND CONTROL BY 1990

Experiment Groupings:

<u>Title</u>: 1. Modular Instrument Pointing Technology Laboratory (MIPTL)

Individual Experiments:

a. Optical Correlator Landmark Tracker
b. Video Correlator Landmark Tracker
c. Video Inertial Pointing System for Shuttle Astronomy Payloads

<u>Title</u>: 2. Inertial Components Flight Test Facility

Individual Experiments:

a. Low Gravity Accelerometer Testing
b. Redundant Strapdown Laser Inertial Measurement Unit for Space Missions

<u>Other Experiments</u>:

3. Stray Light Rejection Testing

4. Attitude Control of a Flexible Structure

5. Figure Control of Large Deformable Structures

6. Free Flying Interferometer

<u>Major Thrust</u> PROVIDE A HUNDRED-FOLD INCREASE IN HUMAN'S PRODUCTIVITY IN SPACE THROUGH LARGE-SCALE TELEOPERATOR APPLICATION BY 1990

<u>Experiments</u>: 1. Teleoperator Orbiter Bay Experiments (TOBE)

2. Earth Orbital Teleoperator System (EOTS)

TABLE I SHUTTLE PAYLOAD EXPI MENT AND EXPERIMENT GROUPING

NAVIGATION GUIDANCE & CONTROL

SHUTTLE EXPERIMENTS	OD/MD +	JUSTIFICATION: NEED SPACE ENVIRONMENT	JUSTIFICATION: SHUTTLE COST EFFECTIVE	JUSTIFICATION: REQUIRED FOR USER ACCEPTANCE
LOW COST NAVIGATION	OD	✓	✓	
SCANNING LASER RADAR	MD		✓	✓
STRAY LIGHT REJECTION	MD		✓	
LOW G ACCELEROMETERS	MD	✓	✓	
REDUNDANT STRAPDOWN IMU	MD			✓
OPTICAL CORRELATOR LANDMARK TRACKER	MD		✓	✓
VIDEO CORRELATOR LANDMARK TRACKER	MD		✓	✓
VIDEO INERTIAL POINTER	MD		✓	✓
ATTITUDE CONTROL OF FLEXIBLE SPACECRAFT	MD	✓	✓	
FIGURE CONTROL OF LARGE STRUCTURES	MD	✓	✓	
TELEOPERATOR ORBITAL BAY EXPERIMENT	MD	✓		✓
EARTH ORBITAL TELEOPERATOR SYSTEM	MD	✓		✓
MODULAR INSTRUMENT POINTING TECHNOLOGY LABORATORY (MIPTL)	MD	✓	✓	
INERTIAL COMPONENTS FLIGHT TEST FACILITY	MD	✓		✓
FREE FLYING INTERFEROMETER ELEMENTS	MD	✓		✓

(+ MD = MISSION DRIVEN, OD = OPPORTUNITY DRIVEN)

TABLE II - EXPERIMENT JUSTIFICATION AND CATEGORIZATION

OUTLOOK FOR SPACE	OFFICE OF SPACE SCIENCE (USER INPUTS)	OFFICE OF APPLICATIONS (USER INPUTS)
(1) VERY LONG LIFE COMPONENTS AND SYSTEMS	(2) LONG LIFE, SELF REPAIRING SPACECRAFT SYSTEMS	
(3) AUTONOMOUS SPACECRAFT AND VEHICLES	(4) ELECTRONIC GUIDANCE AND CONTROL SYSTEMS FOR NEAR AUTOMATED LONG MISSION LIFE	
	(6) AUTOMATED RENDEVOUS AND DOCKING SYSTEM TECHNIQUES	
	(7) AUTOMATIC S/C RENDEVOUS - MARS SAMPLE RETURN	
	(8) COMET AND ASTEROID RENDEVOUS AND SAMPLE RETURN MISSION	
	(9) IMPROVED SURFACE MOBILITY AND NAVIGATION FOR UNMANNED ROVERS	
		(10) IMPROVED DETERMINA POSITION ACCURACY O SPACE STATIONS
		(11) DEVELOP SPACEBORNE ACCLEROMETERS OF I ACCURACY FOR MEASU INFLUENCE OF DRAG O STUDY SATELITES
(12) PRECISION NAVIGATION		

TABLE III RELATIONSHIP BETWEEN OUTLOOK FOR SPACE, USER INPUTS AND TECHNOLOGY REQUIREMENTS

FOLDOUT FRAME 1

...ER INPUTS OFFICE OF ...ICATIONS	OFFICE OF MANNED SPACE FLIGHT	MAJOR THRUST	DOTR #	
	(5) LONG LIFETIME RELIABILITY ASSURANCE		14 19 21 36 24 1 25	STELLAR I... HIGH RESO... CONTINUE... RADIATION... MISSIONS RATE GYR... LOW COST... REDUNDAN...
			3	SCANNING...
		REDUCE MISSION SUPPORT BY 50% THROUGH AUTONOMOUS OPERATIONS BY 1990	5 7 8	AUTONOM... COMET AN... COMETARY...
			9	AUTOMATE...
...ERMINATION OF THE ...URACY OF ORBITAL ...NS				
...EBORNE ...ERS OF IMPROVED ...R MEASUREMENT OF THE ...DRAG ON GRAVITY ...ES			23	LOW "G" A...
			6 2 35	Δ VLBI AN... APPROA... SPACEC... CONT...

FOLDOUT FRAME 1

MAJOR THRUST	DOTR #	TECHNOLOGY REQUIREMENTS
	14	STELLAR II
	19	HIGH RESOLUTION LONG LIFE INERTIAL REFERENCE UNIT
	21	CONTINUED DEVELOPMENT OF DIGITAL REBALANCE ELECTRONICS
	36	RADIATION ATTITUDE CONTROL FOR EXTENDED LIFE PLANETARY MISSIONS
	24	RATE GYRO PACKAGE
	1	LOW COST NAVIGATION INDEPENDENT OF NASA TRACKING FACILITIES
	25	REDUNDANT STRAPDOWN IMU FOR SPACE MISSIONS
	3	SCANNING LASER RADAR
	5	AUTONOMOUS GUIDANCE AND NAVIGATION
E MISSION SUPPORT BY 50% GH AUTONOMOUS OPERATIONS	7	COMET AND ASTEROID EPHEMERIDES
	8	COMETARY INTERCEPT MISSION
	9	AUTOMATED SPACECRAFT (ROVERS)
	23	LOW "G" ACCELEROMETER TEST FACILITY
	6	Δ VLBI AND PULSAR NAVIGATION
	2	APPROACH GUIDANCE FOR A SPINNING SPACECRAFT
	35	SPACECRAFT SURFACE FORCE CONTROL (SURFCON) AND ATTITUDE CONTROL SYSTEM

FOLDOUT FRAME 3

USER INPUTS

OUTLOOK FOR SPACE	OFFICE OF SPACE SCIENCE	OFFICE OF APPLICATION
		(13) SPACECRAFT ATTITU CONTROL OR DETERM NEEDED TO ONE (1) A FOR EARTH POINTING
	(14) IMAGING TECHNIQUES WITH CARTOGRAPHIC ACCURACY	
(15) COMMUNICATIONS ELEMENTS		(16) THE DEVELOPMENT OF SYSTEMS (BETWEEN EM RECEIVER) CAPABLE OF DEVICES AT 1,000 KM TO ACCURACY OF A FEW AR SECONDS
(17) SPACE ENERGY CONVERTERS		
(18) LARGE, CONTROLLABLE LIGHTWEIGHT STRUCTURES	(19) LARGE STRUCTURES IN SPACE WITH EXTREMELY ACCURATE POSITION AND ATTITUDE KNNOWLEDGE AND CONTROL	(20) PRECISION POINTING FO STRUCTURES AND AF RA
		(22) REFINEMENT OF LOW-RA INTERFEROMETRIC TECH TO PERMIT LOCATION OF CONTINENTS WITHIN A F
(24) COMMUNICATION - NAVIGATION		

FOLDOUT FRAME

TABLE III continued

OFFICE OF APPLICATION	OFFICE OF MANNED SPACE FLIGHT	MAJOR THRUSTS	DOTR #	
ECRAFT ATTITUDE TROL OR DETERMINATION IS ED TO ONE (1) ARC SECOND EARTH POINTING			26	OPTICAL CO
			27	VIDEO CORR
ELOPMENT OF CLOSED LOOP S (BETWEEN EMITTER AND ER) CAPABLE OF POINTING S AT 1,000 KM TO AN CY OF A FEW ARC S		II INCREASE MISSION BENEFITS THROUGH A TEN-FOLD POINTING AND CONTROL IMPROVEMENT BY 1990	17	OPTICAL ST STAR TRAC
			18	STRAY-LIGH
ON POINTING FOR LARGE URES AND ARRAYS			31	VIDEO INER PAYLOADS
	(21) LARGE SPACE BASED POWER SYSTEMS			
IENT OF LOW-RANGE EROMETRIC TECHNIQUES IIT LOCATION OF THE ENTS WITHIN A FEW CM			32	ATTITUDE C
	(23) LARGE VOLUME/LONG RANGE COMMUNICATIONS		34	HIGH ACCU BODY S/C
			33	FIGURE CON
			38	MEASUREM

FOLDOUT FRAME

MAJOR THRUSTS	DOTR #	TECHNOLOGY REQUIREMENTS
	26	OPTICAL CORRELATOR LANDMARK TRACKER
	27	VIDEO CORRELATOR LANDMARK TRACKER
REASE MISSION BENEFITS GH A TEN-FOLD POINTING ONTROL IMPROVEMENT BY	17	OPTICAL STANDARDIZATION AND IMPROVED TUBE DESIGN FOR STAR TRACKER
	18	STRAY-LIGHT REJECTION
	31	VIDEO INERTIAL POINTING SYSTEM FOR SHUTTLE ASTRONAUT PAYLOADS
	32	ATTITUDE CONTROL OF FLEXIBLE SPACECRAFT CONFIGURATIONS
	34	HIGH ACCURACY INSTRUMENT POINTING SYSTEM FOR FLEXIBLE BODY S/C
	33	FIGURE CONTROL OF LARGE DEFORMABLE STRUCTURES
	38	MEASUREMENT AND CONTROL OF LONG BASELINE STRUCTURES

FOLD

OUTLOOK FOR SPACE	USERS INPUTS OFFICE OF SPACE SCIENCE	INPUTS OFFICE O APPLICAT
(26) LUNAR RESOURCE RECOVERY, PROCESSING AND SPACE MANEUVERING		
	(29) SURVIVABLE HARD AND SEMI-HARD LANDED SCIENCE STATIONS	

FOLDOUT FRAME

TABLE III CONCLUDED

INPUTS

OFFICE OF APPLICATIONS	OFFICE OF MANNED SPACE FLIGHT	MAJOR THRUST
	(25) IN SPACE CONSTRUCTION TECHNIQUES (27) ORBITOR ASSEMBLY/MAINTENANCE, SERVICE/REPAIR (28) REMOTE CONTROLLED MANIPULATORS	III ENHANCE HUMAN'S PRODUCTIVITY IN SPACE THROUGH LARGE-SCAE TELEOPERATOR APPLICATION BY 1990
		BASIC IMPROVEMENTS IN NAVIGATION COMPONENTS AND TECHNIQUES LEADING TO IMPROVED RELIABILITY AND LOWER COST

FOLDOUT FRAME 2

MAJOR THRUST	DOTR #	TECHNOLOGY REQUIREMENTS
III ENHANCE HUMAN'S PRODUCTIVITY IN SPACE THROUGH LARGE-SCAE TELEOPERATOR APPLICATION BY 1990	44	MULTIPURPOSE PANEL
	43	SATELITE SERVICING
	42	SUPERVISORY CONTROL OF REMOTE MANIPULATORS
	41	SPACE TELEOPERATOR TECHNOLOGY
	10	ROBOTIC DECISION MAKING AND PLANNING
	11	ROBOTIC SCENE ANALYSIS
	12/45	END EFFECTOR SENSORS FOR ROBOT AND TELEOPERATOR MANIPULATORS
	46	TELEOPERATOR CONTROLLERS
	47	WRIST MECHANISMS
	48	MINIATURE TV CAMERA
	49	IMAGE ENHANCEMENT
	50	VIDEO SIGNAL COMMUNICATIONS
	30	HARD LANDER CONTROL FOR AIRLESS PLANETS
BASIC IMPROVEMENTS IN NAVIGATION COMPONENTS AND TECHNIQUES LEADING TO IMPROVED RELIABILITY AND LOWER COST	20	CRYOGENIC GYROSCOPES FOR SPACE AND AIRCRAFT NAVIGATION*
	15	INTENSIFIED SOLID STATE IMAGING DEVICE*
	16	CHARGE INJECTION DEVICES FOR LOW LIGHT LEVEL IMAGING
	4	DEVELOPMENT OF LOW COST NAVIGATIONAL COMPONENTS
	22	HIGH RESOLUTION ATTITUDE SENSOR
	28	OPTICAL INERTIAL REFERENCE*
	37	FLUID MOMENTUM GENERATOR*
	39	MAGNETIC LARGE ARRAY AND SHAPE MANAGEMENT*

*Referred to Basic Research Panel

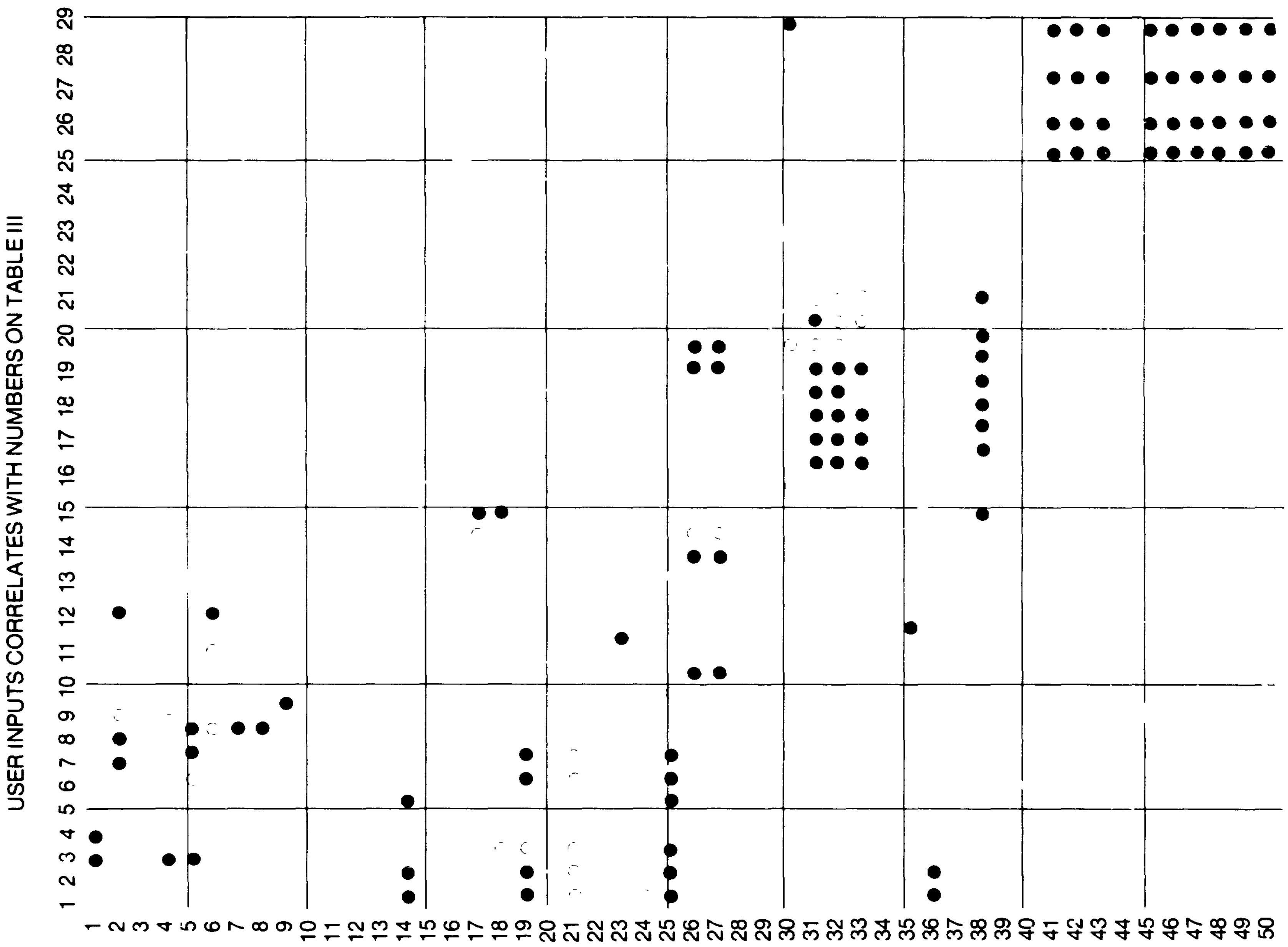


TABLE III-A CROSS CORRELATION OF USER REQUIREMENTS AND DOTR'S

EXPERIMENT RESUMES

LOW COST NAVIGATION INDEPENDENT OF NASA TRACKING FACILITIES

The proposed experiment would fly high quality aircraft navigation gear (receiver/transmitter) to survey the signal reception from orbit of the several existing navigation nets for aircraft use around the world. When signal reception characteristics are measured and understood, future Earth orbiting satellites could be designed with the capability of moderately accurate, near autonomous navigation thus reducing the work load on the NASA tracking net.

This experiment should be considered to lead to opportunity driven technology and would be used by survey and monitoring missions.

References:

1. "Definition of Technology Requirements" No. 1

2. "Future Payload Technology Testing and Development Requirement" No. NGC-1

SCANNING LASER RADAR

The scanning laser radar provides complete six-degree-of-freedom sensing at short range for rendezvous and docking application. A shuttle experiment will provide the unique lighting conditions of space and the freedom of motion that is expensive to provide in an earth-bound facility. The technology is applicable to any rendezvous and docking missions where autonomous operation is required, and particularly to the Space Tug.

References:

1. "Definition of Technology Requirements" No. 2

2. "Future Payload Technology Testing and Development Requirement" No. NGC-3

STRAY-LIGHT REJECTION

The principle purpose of this effort is to provide a means of design verification for new sun and earth shade designs. A secondary purpose is to verify present day design procedures. As discussed in the DOTR and its abstract the attenuation characteristics are very difficult to obtain in earth based facilities; in fact, in the past it has been recommended that a new facility be set up to evaluate sun shades. The experiment(s) would consist of various new design configurations and accompanying photo sensors to fly aboard Shuttle. This package would be picked up by the remote manipulator and rotated to various angles relative to Shuttle or the entire vehicle allowed to rotate. The degree of precision required from the test would probably dictate the mode of operation. Comparison of these results with design goals would eventually improve and refine design procedures. It should be recognized that the attendant star tracker may or may not be flown with the sun shade dependent upon whether attenuation measurements, operational characteristics, or both are desired.

The principal benefactor from such tests are the users of star trackers who wish to push their instruments closer to the sun. Such tests will also allow sun shade size (hence weight and volume) to be reduced to the minimum.

References:

1. "Definition of Technology Requirements" No. 18

2. "Future Payload Technology Testing and Development Requirement" No. NGC-3

LOW - G ACCELEROMETER TESTING

The proposed test facility in a zero-g environment will enable development of accelerometers with measurement capability of 10^{-9}g or less. This level of accuracy is required to be able to measure non-gravitational S/C forces which produce accelerations of this order of magnitude. The principal advantages of in-orbit test facilities are that elaborate and costly seismic isolation techniques in the laboratory would not be needed, and to date such laboratory devices have never enabled the required level of accuracy, which would be attainable in-orbit.

This technology is required for earth and ocean physics missions for measurement of the effect of drag on gravity study satellites.

References:

1. "Definition of Technology Requirements" No. 23

2. "Future Payload Technology Testing and Development Requirement" No. NGC-4

REDUNDANT STRAPDOWN LASER INERTIAL MEASUREMENT UNIT

The IMU includes six laser gyros and six accelerometers in a dodecahedron configuration. In the flight experiment they will be evaluated and demonstrated in the zero-g, vacuum space environment. This demonstration is justified by the novel and new nature of the laser gyro. The IMU is potentially applicable to interplanetary missions where a highly reliable navigation sensor is required.

References:

1. "Definition of Technology Requirements" No. 25

2. "Future Payload Technology Testing and Development Requirement" No. NGC-5

OPTICAL CORRELATOR LANDMARK TRACKER

AND

VIDEO CORRELATOR LANDMARK TRACKER

These two devices are discussed together since their end goal is to provide the users (OA and OSS) with the capability of pointing to predetermined targets on the earth very accurately with only modest ephemeris and attitude information available. Present techniques require precise ephemeris and attitude data which are then used to calculate pointing direction. An additional attribute of either of these devices is that it can be combined directly into the optical path of the sensing telescope (or RF Receiver of a large antenna) in such a way that the pointing direction of the sensing structure (optics/antenna) is directly monitored without recourse to transfering a pointing direction from an independent sensor. This will allow earth pointing instruments to use the earth as a cooperative target the same as celestial sensors use stars and will allow the users of one arc-second pointing accuracy (OA) to be met. In order to properly evaluate these devices, it will be necessary to test aboard a shuttle flight which can provide accurate instrument pointing capability toward the earth. This will allow an assessment of their tolerance to cloud cover, lighting variation and look angle, factors to which they theoretically have a large tolerance.

While these devices offer solutions to similar problems,

(cont. on page 2)

it should be pointed out that the technology necessary for their implementation is significantly different. They, therefore provide complimentary approaches to a different and important problem.

References:

1. "Definition of Technology Requirements" Nos. 26 and 27

2. "Future Payload Technology Testing and Development Requirements" Nos. NGC-6 and NGC-7

VIDEO INERTIAL POINTING (VIP) SYSTEM

The Video Inertial Pointing (VIP) System utilizes a video sensor to provide three axis error signals for pointing and stabilization of an astronomical telescope. In addition, the video sensor will drive a display for use in starfield/target identification and manual control. A shuttle experiment is required to demonstrate the VIP system in a meaningful operational test to ensure user acceptance. The ability to track the very dim stars and astronomical targets can only be demonstrated above the earth's atmosphere. The operational test of the VIP system technology will support the pointing and acquisition requirements of shuttle-attached astronomy payloads including the Shuttle Infrared Telescope Facility (SIRTF) and the Shuttle UV/Optical Telescope (SUOT). The VIP system technology requirements and shuttle experiment are described in more detail in the references shown below.

References:

1. "Definition of Technology Requirements" No. 31
2. "Future Payload Technology Testing and Development Requirement" No. NGC-8

ATTITUDE CONTROL OF FLEXIBLE SPACECRAFT CONFIGURATIONS

This experiment demonstrates the attitude control of flexible structures in space utilizing advanced control and modeling techniques designed to minimize the dynamic structural response. Such a control system could provide an accurate attitude environment that would increase the mission success of a broad range of sensors and systems. This experiment requires space testing to obtain the zero-g environment and is an outgrowth of user requirements from OSS, OA and OMSF.

References:

1. "Definition of Technology Requirements" No. 32
2. "Future Payload Technology Testing and Development Requirement" No. NGC-9

FIGURE CONTROL OF LARGE DEFORMABLE STRUCTURES

This experiment explores figure control of large flexible structures in space by actually deploying controlled flexible arrays. Such shape control is necessary to achieve efficiency, high gain, and improved bandwidth and resolution in sensors and antenna arrays. This experiment requires space testing to obtain the zero-g environment and is an outgrowth of user requirements from OSS and OA.

References:

1. "Definition of Technology Requirements" No. 33
2. "Future Payload Technology Testing and Development Requirement" No. NGC-10

TELEOPERATOR ORBITER BAY EXPERIMENT (TOBE)

The TOBE will be the first in a series of space teleoperator experiments that will demonstrate the man-machine capability in space for manipulating and servicing through remote control -- (To be conducted in Shuttle Bay). The basic TOBE will consist of a manipulator, docking adapter/grappler, visual and R.F. telemetry/communication systems, plus a task board.

The TOBE will assess these systems and their interface hardware components in the environment parameters of space such as zero-g gravity, vacuum and extreme thermal and lighting conditions. The associated task board will contain a variety of hardware components, cable connectors, modules for exchange, etc., for the purpose of demonstrating the effectiveness, dexterity and handling ability of the hand controllers, manipulators and end effectors under a gravity free situation remotely through a visual system. In addition to the above, the TOBE will also be utilized to assess maintenance, servicing, design and operational concepts for future space teleoperators.

The technology being developed by these experiments will support a wide variety of OMSF shuttle missions and payloads.

References:

1. "Definition of Technology Requirements" Nos. 41 through 50

2. "Future Payload Technology Testing and Development Requirement" No. NGC-11

EARTH ORBITAL TELEOPERATOR SYSTEMS (EOTS)

The EOTS will be the second generation of space teleoperator experiments. It will consist of the same type equipment as the TOBE (manipulator, docking adapter/grappler, visual and R.F. telemetry/communication systems) plus a navigation, guidance and control, and propulsion system.

The EOTS will assess the above systems in a free space, gravity free environment and provide the means to evaluate a "Free Flying Teleoperator". A summary of the benefits afforded by the EOTS can be provided by an investigation of applications of EOTS potential capabilities. Some of these benefits are: Monitor/Inspect -- The EOTS can provide an examination of areas not currently possible with the STS systems. It can also provide a panoramic view of any STS activities such as payload deployment or EVA -- Deploy/Retrieve. It can assist in the recovery of payloads where dynamic state might compromise the orbiter's safety. In addition, the EOTS can deploy the payload at a distance from the orbiter, reducing contamination levels.

Experiment Support Servicing -- The versatility of the mechanisms allows much greater coverage in serviceable payload design. The elimination of payload bay servicing dedicated equipment provides more space for payloads. The payloads can employ EOTS capabilities rather than designing their own. When required, the EOTS can functionally replace EVA activities.

Assembly -- EOTS can replace the man for tasks handling

(cont. on page 2)

massive objects that might be hazardous. It can also act as a portable workstation providing lighting, tool storage, and temporary storage for removal parts.

The technology being developed by this experiment will support a wide variety of OMSF shuttle missions and payloads.

References:

1. "Definition of Technology Requirements" Nos. 41 through 50

2. "Future Payload Technology Testing and Development Requirement" No. NGC-12

MODULAR INSTRUMENT POINTING TECHNOLOGY LABORATORY (MIPTL)

The Modular Instrument Pointing Technology Laboratory (MIPTL) provides a facility for performing a variety of experiments associated with instrument pointing technology. The facility would consist of a basic mount, stabilization subsystems, and associated controls and displays. This facility would support several of the experiments that have been proposed and the facility has the potential to support technology advancement over a long time period. The presently identified experiments that would use MIPTL are referenced below; these experiments support a broad range of technology requirements and NASA user offices.

References:

1. "Future Payload Technology Testing and Development Requirement" No. NGC-13

Related Experiments:

1. Optical correlator landmark tracker, No. NGC-6
2. Video correlator landmark tracker, No. NGC-7
3. Video Inertial Pointing System for Shuttle Astronomy Payloads, No. NGC-8

INERTIAL COMPONENTS FLIGHT TEST FACILITY

This facility (module) is required to evaluate advanced navigation components and would be used over a period of many years. This facility is essentially a "free flyer" on board the shuttle or space lab. This module would be released from the shuttle (to isolate disturbances) inertially stabilized and the shuttle flown so as to station keep with the module. Within this facility it would be possible to evaluate a variety of components such as low "g" accelerometer, gyroscope components, and inertial measurement units.

References:

1. "Definition of Technology Requirements" Nos. 4, 5, and 14

2. "Future Payload Technology Testing and Development Requirements" Nos. 23 and 25

FREE FLYING INTERFEROMETER

This space experiment evaluates the use of interferometers composed of free flying receivers for locating mobile ground platforms and stellar radiometric sources. This requires a space experiment to realistically evaluate accuracy and ground beacon power requirements. This experiment is in response to the Outlook for Space. Objective 034 - Communication - Navigation which highlights the need for locating, controlling, and performing search and rescue for mobile ground platforms (e.g., ships and aircraft).

References:

1. "Definiti[illegible] Technology Requirements" No. 38

2. "Future P[illegible]load Technology Testing and Development Requirement" No. NGC-15

D. FUTURE PAYLOAD TECHNOLOGY TESTING AND DEVELOPMENT REQUIREMENT FORMS

V. Relation to Current Technology Program

A. Introduction

The development of technology requirements and shuttle experiments in the previous sections leads naturally to the question of how the current technology program relates to these requirements. To answer this question, a roadmap of the current technology program was generated and compared to the technology requirements.

B. Roadmap of the Current Technology Program

The roadmap which includes all RTOPS which are applicable to the navigation, guidance and control disciplines is Figure 3. The RTOPS group naturally into major thrusts that were identified in Section II. The listing of RTOPS and the associated roadmap are given in Table IV. The technology requirements identified in Section III are compared to the current program RTOP numbers in Tables V, VI, VII, and VIII.

C. Relation of Current Program to Technology Requirements and Shuttle Experiments

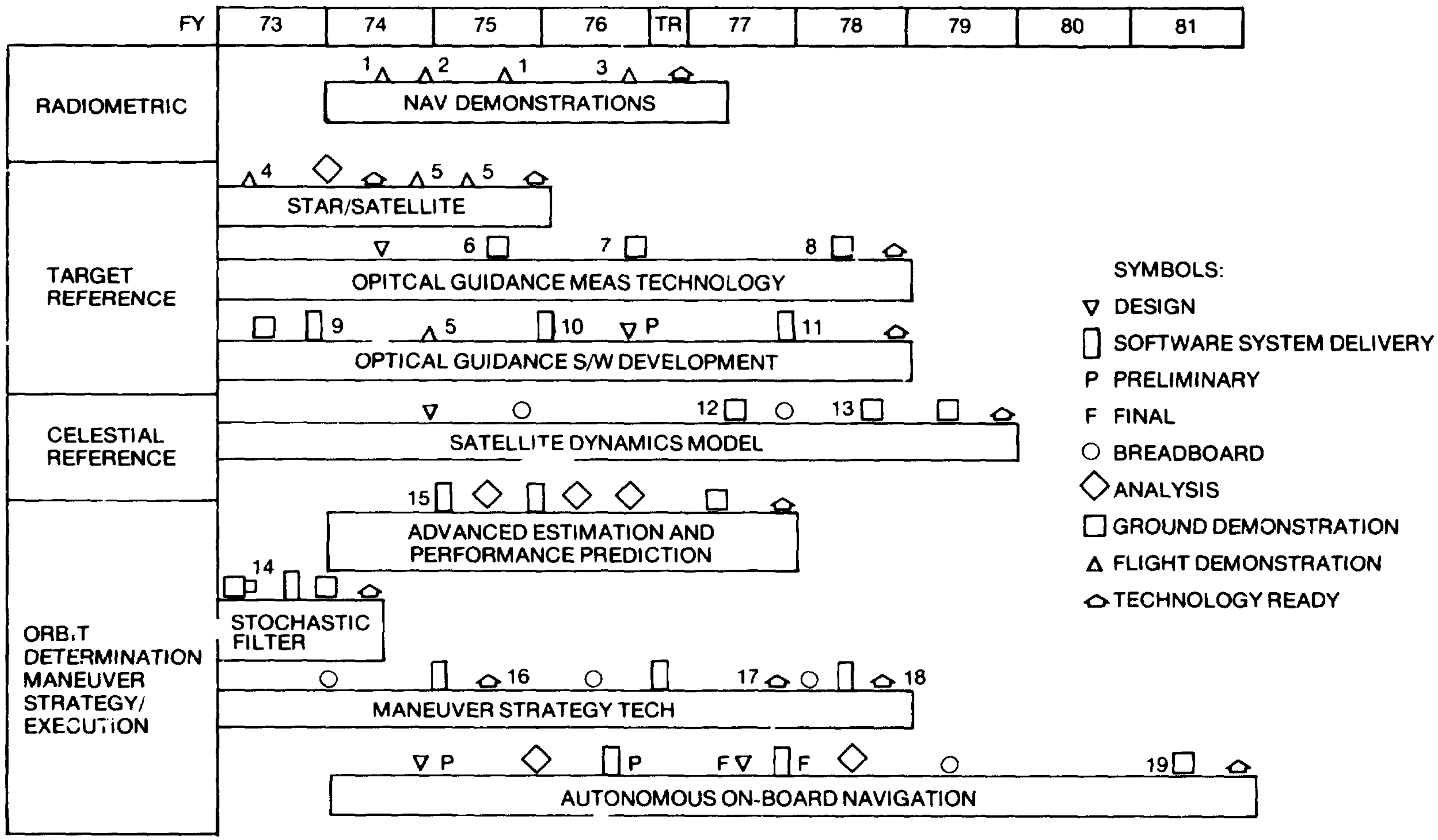
Based on the roadmap of the on-going program and the charts comparing this to the technology requirements generated during the Workshop, several comments are required:

1. There was variation as to the input of technology requirements to the workshop. Some on-going technology programs that may require or benefit from a shuttle experiment were not submitted as technology requirements. No attempt was made to work backwards during the workshop and consider these on-going programs for possible experiments or to determine how these programs match the workshop user requirements.

2. No attempt was made to establish priorities for the shuttle experiments or to relate their importance to additional work for technology requirements not covered by the on-going technology program.

3. Several of the GN&C shuttle experiments are interrelated with other discipline working groups. For example the pointing and control experiments relate closely to the sensors and data acquisition, and the MIPTL (Modular Instrument Pointing Technology Laboratory) could be used in conjunction with advance sensors such as the Advanced Technology Radiometer. The experiments proposed in the structures and arrays area must be jointly developed with the structures discipline.

NAVIGATION ROADMAP



NOTES:
1. MVM '73 S/X
2. MVM '73 MULTI STATION
3. V'75 COMBINED S/X-MULTISTATION
4. MM '71 IN-ORBIT
5. MVM '73 BRIGHT OBJ/DIM STAR
6. SAT/STAR W/SELENIUM VIDICON
7. COMET
8. AUTOMATIC SENSING/EXTRACTION
9. MANUAL INTERACTION
10. GROUND-BASED AUTOMATED
11. ON-BOARD AUTOMATED (PRELIM)
12. TEST VS NUMERICAL INTEGRATION
13. TEST BY FIT TO OBSERVATIONS
14. SEQUENTIAL FILTERS
15. PERFORMANCE PREDICTION SOFTWARE
16. INTERPLANETARY
17. ORBITER
18. RENDEZVOUS
19. READY FOR MJO'85

Fig. 3: NAVIGATION, CONTROL ROBOTICS/TELEOPERATOR ROADMAPS

CONTROL ROADMAP

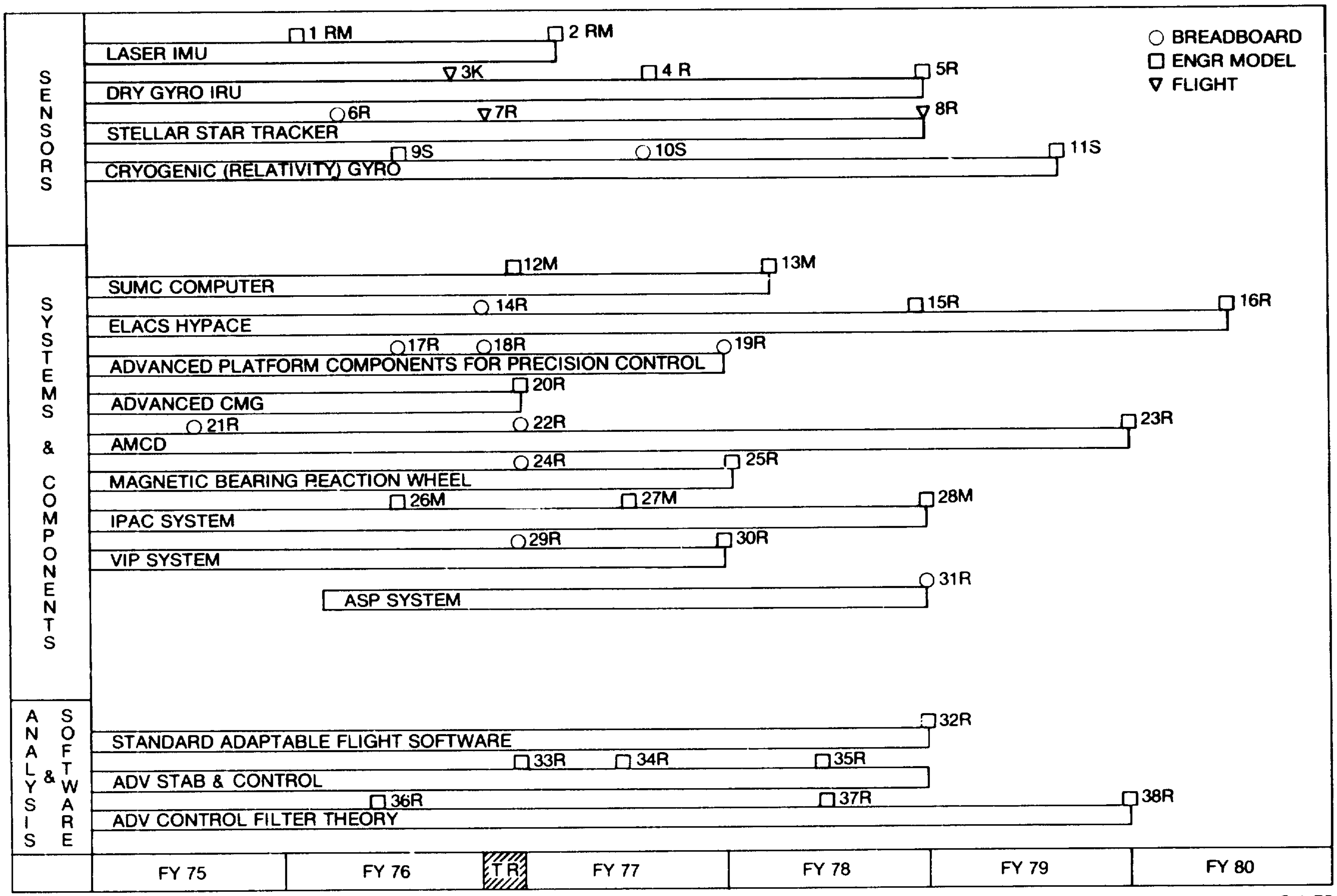


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Fig.: NAVIGATION, CONTROL, ROBOTICS/TELEOPERATOR ROADMAPS (Cont.)

ROBOTICS/TELEOPERATOR ROADMAP

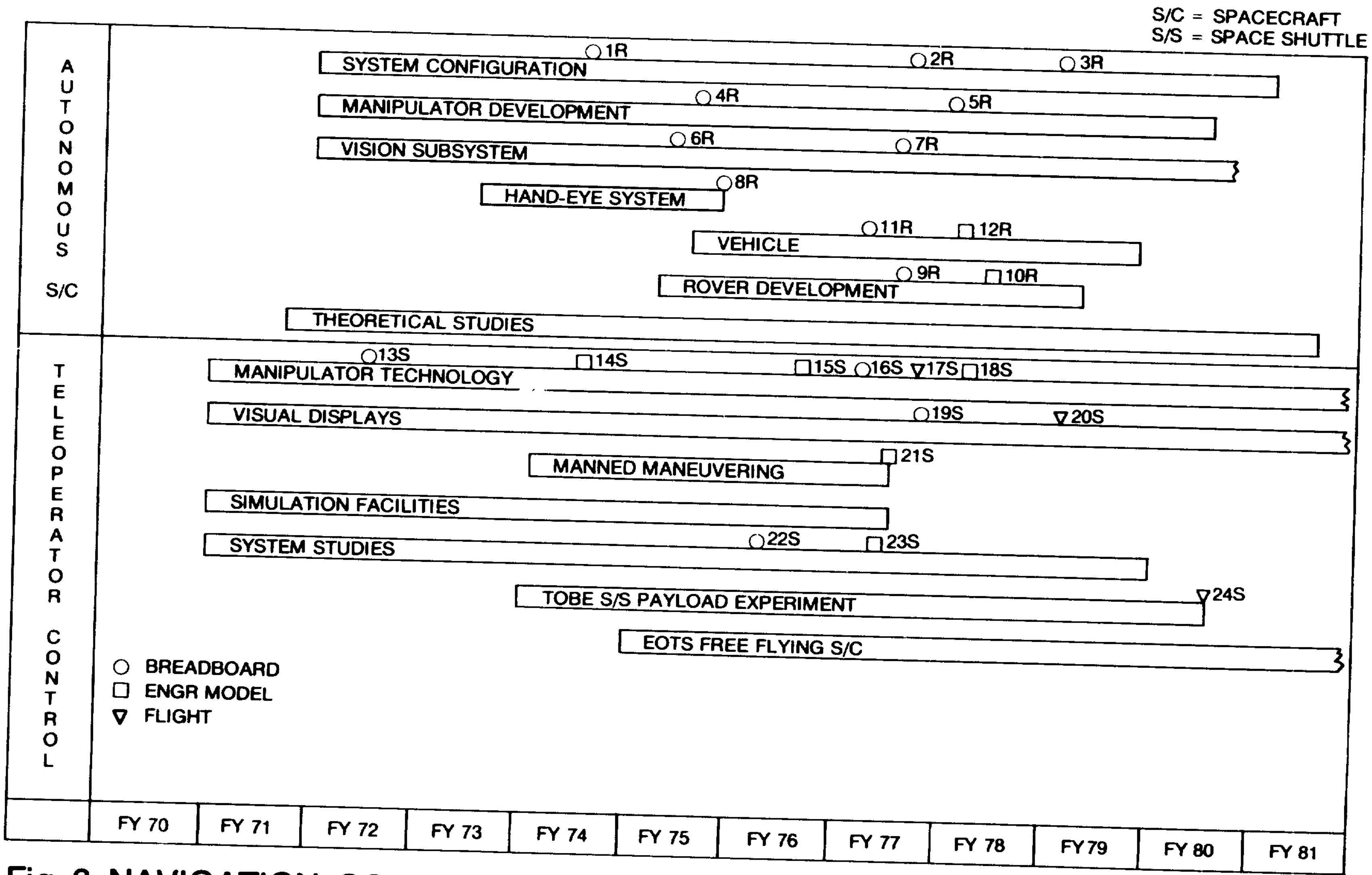


Fig. 3: NAVIGATION, CONTROL, ROBOTICS/TELEOPERATOR ROADMAPS (Cont.)

ATTACHMENT TO FIGURE 3

CONTROL ROADMAP LEGEND

MILESTONE	END ITEM		CENTER
1RM	Laser IMU System Operational Test	909-55-10/506-19-11	MSFC
2RM	Redundant Laser IMU System Test	909-55-10/506-19-11	MSFC
3K	Standard (MJS) DRIRU Prototype	-	JPL
4R	Long Life DRIRU Gyro	506-19-14	JPL
5R	Long Life DRIRU	506-19-14	JPL
6R	Breadboard VIP Stellar Tracker	506-19-15	JPL
7R	ELACS Stellar Tracker Breadboard	506-19-14	JPL
8R	ELACS Stellar Technology Readiness	506-19-14	JPL
9S	Definition of Flight Experiment Mission	188-41-54	MSFC
10S	Prototype Gyro Testing Complete	188-41-54	MSFC
11S	High Tolerance Model Available	188-41-54	MSFC
12M	IMS SUMC Computer Integration	909-54-10/909-54-33	MSFC
13M	Fault Tolerant SUMC Test	909-54-10/909-54-33	MSFC
14R	ELACS Electronics Breadboard	506-19-14	JPL
15R	Fault Tolerant ELACS Electronics	506-19-14	JPL
16R	ELACS Technology Readiness	506-19-14	JPL
17R	2 Axis Bearing Integration with Ironless Motor	506-19-12	GSFC
18R	Small Scale Isolation Platform	506-19-12	GSFC
19R	Platform Soft Isolator Evaluation	506-19-12	GSFC
20R	Final Testing of Second Generation CMG	506-19-13	LaRC
21R	AMC D Laboratory Prototype	506-19-13	LaRC
22R	AMCD Hardware Test Complete	506-19-13	LaRC

ATTACHMENT TO FIGURE 3 (CONT'D.)

CONTROL ROADMAP LEGEND

MILESTONE	END ITEM	RTOP	CENTER
23R	Completion of 2 Axis AMCD	506-19-13	LaRC
24R	Breadboard Mag. Bearing Reaction Wheel	506-19-14	JPL
25R	Mag. Bearing Reaction Wheel Tech. Readiness	506-19-14	JPL
26M	IPACS Prototype Wheel	909-81-08	
27M	Composite Rotor	909-74-35/910-35-02	LaRC
28M	Composite Rotor Testing Complete	909-74-35/910-35-02	LaRC
29R	VIPS Stage II System Test	506-81-08	AMES
30R	VIPS Stage III System Test	506-81-08	AMES
31R	Annular Suspension & Pointing System Model	506-19-13	LaRC
32R	Standardized Software Library	506-19-15	LaRc
33R	Define Tug Deployment Techniques	909-08-51	MSFC
34R	Define IPS Ultimate Pointing Perf.	909-08-51	MSFC
35R	Define IPS Digital Controller Design	909-08-57	MSFC
36R	Optimum Filter Developed	506-19-14	JPL
37R	Suboptimal Filter Options Developed	506-19-14	JPL
38R	Best Suboptional Filter Selected	506-19-14	JPL

MAJOR THRUSTS

I AUTONOMOUS OPERATIONS

II POINTING AND CONTROL

III TELEOPERATORS

I AUTONOMOUS OPERATION

REFERENCE RTOPS

JPL	506-19-21	Optical Guidance, Multi-Maneuver Strategy, on-board Nav, flt experiments
JPL	186-68-52	CCD TV Camera
GSFC	310-10-22	Mission Support Computing Systems & Techniques
GSFC	310-10-26	Attitude-Orbit Analysis
GSFC	310-10-43	Advanced LASER Ranging Systems Development
MSFC	180-17-54	Guidance Computer Technology
JPL	186-68-74	NAV & Mission Analysis - SEP
LaRC	506-19-22	Video Guidance System
HQTRS	506-19-31	Rover NAV, SIM, Scene Analysis
JPL	506-19-32	Stereo Sensors, Planetary Rover Model, etc.
JPL	186-68-55	Mars Roving Vehicle
MSFC	180-17-50	System Perf. & Tech. Assessment for Unmanned Missions

TABLE IV - ROADMAP ORGANIZATION NAVIGATION, GUIDANCE & CONTROL

II. POINTING & CONTROL

A. SENSORS

MSFC	909-55-10/506-19-11	LASER GYRO
MSFC	188-41-54	Cryogenic (Relativity) Gyro
JPL	506-19-14/186-68-54	ELACS, STELLAR & DRIRU
GSFC	188-78-56	IMAGING TECHNOLOGY

B. SYSTEMS & COMPONENTS

MSFC	909-54-10/909-54-33	SUMC
GSFC	506-19-12	Magnetics, Wheels & Bearings
LaRC	506-19-13	Momentum Storage System
JPL	506-19-14/186-68-79	ELACS Electronics & MBRW
LaRC	909-74-35/910-35-02	Integrated Power/Attitude Control
GSFC	909-81-08	Direct Drive Actuator for IPAC
AMES	506-19-15	VIPS System
LaRC	506-19-13	Adaptive Control Software
JPL	506-19-14	ELACS Control System Analysis
MSFC	909-08-51	Stab & Control - Modern Control Tech.

III. TELEOPERATORS

ARC	970-23-20	Advance Manipulators
JSC	970-53-20	Remote Manipulator System
MSFC	970-63-20	Earth Orbital Teleoperator System
JPL	970-83-20	Planetary/Lunar Surface Teleoperators
JSC	975-50-01	Manned Maneuvering Units

TABLE IV - ROADMAP ORGANIZATION NAVIGATION, GUIDANCE & CONTROL (CONT.)

	TECHNOLOGY REQUIREMENTS I. AUTONOMOUS OPERATIONS	CURRENT AND RELATED RTOP NUMBERS
1	Low Cost Navigation Independent of NASA tracking Facilities	Feasibility needs to be determined
2	Approach Guidance From a Spinning Spacecraft	Pre-project or OSS support
3	Scanning Laser Radar	310-10-43
4	Development of Low Cost Navigation Components	No Reprogram for low cost inertial component development
5	Autonomous Guidance and Navigation	506-19-21 506-19-22 186-68-52
6	VLBI and Pulsar Navigation	Candidate for study
7	Comet, Asteroid Ephemerides	Candidate for study
8	Cometary Intercept Navigation and Guidance	Candidate for study
9	Automated Spacecraft	506-19-32 970-63-20 970-83-20
10	Robotic Decision Making and Planning	186-68-55 506-19-32
11	Robotic Scene Analysis	506-19-31
12	End Effector Sensors	970-23-20 970-83-20 970-53-20

TABLE V - TECHNOLOGY REQUIREMENTS/CURRENT PROGRAMS I

TECHNOLOGY REQUIREMENTS

II. POINTING AND CONTROL SENSORS

		CURRENT AND RELATED RTOP NUMBERS
14	STELLAR II (Star Tracker)	506-19-14 186-68-54
15	Intensified Solid State Imaging Device	188-78-56
16	CID for Low Light Level Imaging	506-19-14 186-68-54 186-68-52 188-78-56 (Emphasis on CCD)
17	Optical Standardization and Improved Tube Design for Star Trackers	Believe to be funded by LST
18	Stray-Light Rejection	Consider pre-project funding
19	High Resolution Long Life Inertial Reference Unit	909-55-10 506-19-11
20	Cryogenic Gyroscopes for Space and Aircraft Navigation	188-41-54
21	Continued Development of Digital Rebalance Electronics for Dry-Tuned Rotor Gyros	Believe to be funded
22	High Resolution Attitude Sensor	188-41-54
23	Low-G Accelerometer Evaluation Facility	Facility needs feasibility study
24	Rate Gyro Package	909-55-10 506-19-11

TABLE VI - TECHNOLOGY REQUIREMENTS/CURRENT PROGRAMS II

TECHNOLOGY REQUIREMENTS II. POINTING AND CONTROL SENSORS (continued)		CURRENT AND RELATED RTOP NUMBERS
25	Redundant Strapdown IMU for Space Missions	909-55-10 506-19-11
26	Optical Correlator Landmark Tracker	Feasibility demonstrated could be considered as program addition
27	Video Correlator Landmark Tracker	506-19-22
28	Optical Inertial Reference	Referred to basic research Possible candidate as low cost

TABLE VI - TECHNOLOGY REQUIREMENTS/CURRENT PROGRAMS II

TECHNOLOGY REQUIREMENTS II. POINTING AND CONTROL SYSTEMS AND COMPONENTS		CURRENT AND RELATED RTOP NUMBERS
30	Hard Lander Control System for Airless Planets	Pre-project or OSS support
31	Video Inertial Pointing System for Shuttle Astronomy Payloads	506-19-15 506-19-14 909-08-51
32	Attitude Control of Flexible Spacecraft Configurations	506-19-14
33	Figure Control of Large Deformable Structures	Past work but no current funding
34	High Accuracy Instrument Pointing System for Flexible Body Spacecraft	Candidate for study
35	Spacecraft Surface Force Control (SURFCON) and Attitude Control System	Concept demonstrated could be applied
36	Radiation Attitude Control for Extended Life Planetary Missions	Phenomena observed could be studied for application
37	Fluid Momentum Generator	Referred to basic research Some previous work
38	Measurement and Control of Long Baseline Structures	Candidate for study
39	Magnetic Large Array and Shape Management	Could be studied

TABLE VII - TECHNOLOGY REQUIREMENTS/CURRENT PROGRAMS II

TECHNOLOGY REQUIREMENTS III. HUMAN PRODUCTIVITY		CURRENT AND RELATED RTOP NUMBERS
41	Space Teleoperator Technology	970-63-20 970-83-20 970-53-20 970-23-20
42	Supervisory Control of Remote Manipulators	970-63-20 970-83-20 970-53-20 970-23-20
43	Satellite Servicing	970-63-20 970-83-20 970-53-20 970-23-20
44	Multi-Purpose Panel	970-63-20 970-83-20 970-53-20 970-23-20
45	End Effector Sensors	970-63-20 970-83-20 970-53-20 970-23-20
46	Teleoperator Cortrollers	970-63-20 970-83-20 970-53-20 970-23-20
47	Wrist Mechanism	970-63-20 970-83-20 970-53-20 970-23-20
48	Miniature TV Camera	970-63-20 970-83-20 970-53-20 970-23-20
49	Image Enhancement	970-63-20 970-83-20 970-53-20 970-23-20
50	Video Signal Communications	970-63-20 970-83-20 970-53-20 970-23-20

TABLE VIII - TECHNOLOGY REQUIREMENTS/CURRENT PROGRAMS III

VI. PRESENTATION VIEWGRAPHS

SPACE TECHNOLOGY WORKSHOP
NAVIGATION, GUIDANCE & CONTROL TECHNOLOGY GROUP

W. E. Bachman, JPL, Chairman

MEMBERS:

K. M. Dawson - JPL
W. B. Gevarter - OAST
H. J. Gordon - JPL
W. D. Hibbard - GSFC
W. E. Howell - LaRC
J. D. Johnston - MSFC
J. P. Murphy - ARC

COLLABORATOR:

W. J. Breedlove - ODU
P. Tcheng - ODU

NGC-1

NAVIGATION GUIDANCE & CONTROL

* 12 MAJOR USER REQUIREMENTS IDENTIFIED IN USER GROUP INPUTS AND OUTLOOK FOR SPACE
    * UNMANNED EARTH ORBITAL
    * UNMANNED PLANETARY
    * MANNED MISSIONS

* USER REQUIREMENTS INTO MAJOR THRUSTS

    5 AUTONOMOUS GUIDANCE AND NAVIGATION

    4 POINTING & CONTROL

    3 TELEOPERATORS

NGC-3

NAVIGATION GUIDANCE & CONTROL WORKING GROUP

MAJOR THRUSTS

* REDUCE MISSION SUPPORT COSTS BY 50% THROUGH AUTONOMOUS OPERATIONS BY 1990
* PROVIDE A TEN-FOLD INCREASE IN MISSION OUTPUT THROUGH IMPROVED POINTING AND CONTROL BY 1990
* PROVIDE A HUNDRED-FOLD INCREASE IN HUMAN'S PRODUCTIVITY IN SPACE THROUGH LARGE SCALE TELEOPERATOR APPLICATION BY 1990

NGC-4
081575

NAVIGATION GUIDANCE & CONTROL
MAJOR THRUST - REQUIREMENTS

AUTONOMOUS OPERATIONS

*LONG LIFE COMPONENT & SYSTEMS

*AUTONOMOUS SPACECRAFT & SYSTEMS

*SELF-REPAIRING SPACECRAFT SYSTEMS

*AUTOMATED G&C ELECTRONICS

*LONG LIFE TIME RELIABILITY ASSURANCE

POINTING & CONTROL

*LARGE STRUCTURE & ARRAYS

*INTERPLANETARY INSTRUMENT POINTING

*EARTH ORBITAL POINTING & ATTITUDE CONTROL

*PRECISION INSTRUMENT POINTING FOR MANNED MISSIONS

TELEOPERATORS

*IN-SPACE CONSTRUCTION TECHNIQUES

*ORBITAL ASSY., MAINTENANCE & REPAIRS

*REMOTE CONTROLLED MANIPULATORS

NGC-5
081575

NAVIGATION GUIDANCE & CONTROL

SHUTTLE EXPERIMENTS	OD/MD	JUSTIFICATION: NEED SPACE ENVIRONMENT	JUSTIFICATION: SHUTTLE COST EFFECTIVE	JUSTIFICATION: REQUIRED FOR USER ACCEPTANCE
LOW COST NAVIGATION	OD	✓	✓	
SCANNING LASER RADAR	MD		✓	✓
STRAY LIGHT REJECTION	MD		✓	
LOW G ACCELEROMETERS	MD	✓	✓	
REDUNDANT STRAPDOWN IMU	MD			✓
OPTICAL CORRELATOR LANDMARK TRACKER	MD		✓	✓
VIDEO CORRELATOR LANDMARK TRACKER	MD		✓	✓
VIDEO INERTIAL POINTER	MD		✓	✓
ATTITUDE CONTROL OF FLEXIBLE SPACECRAFT	MD	✓	✓	
FIGURE CONTROL OF LARGE STRUCTURES	MD	✓	✓	
TELEOPERATOR ORBITAL BAY EXPERIMENT	MD	✓		✓
EARTH ORBITAL TELEOPERATOR SYSTEM	MD	✓		✓

NGC-8
081575

NAVIGATION GUIDANCE & CONTROL

TECHNOLOGY REQUIREMENTS

* 47 IDENTIFIED

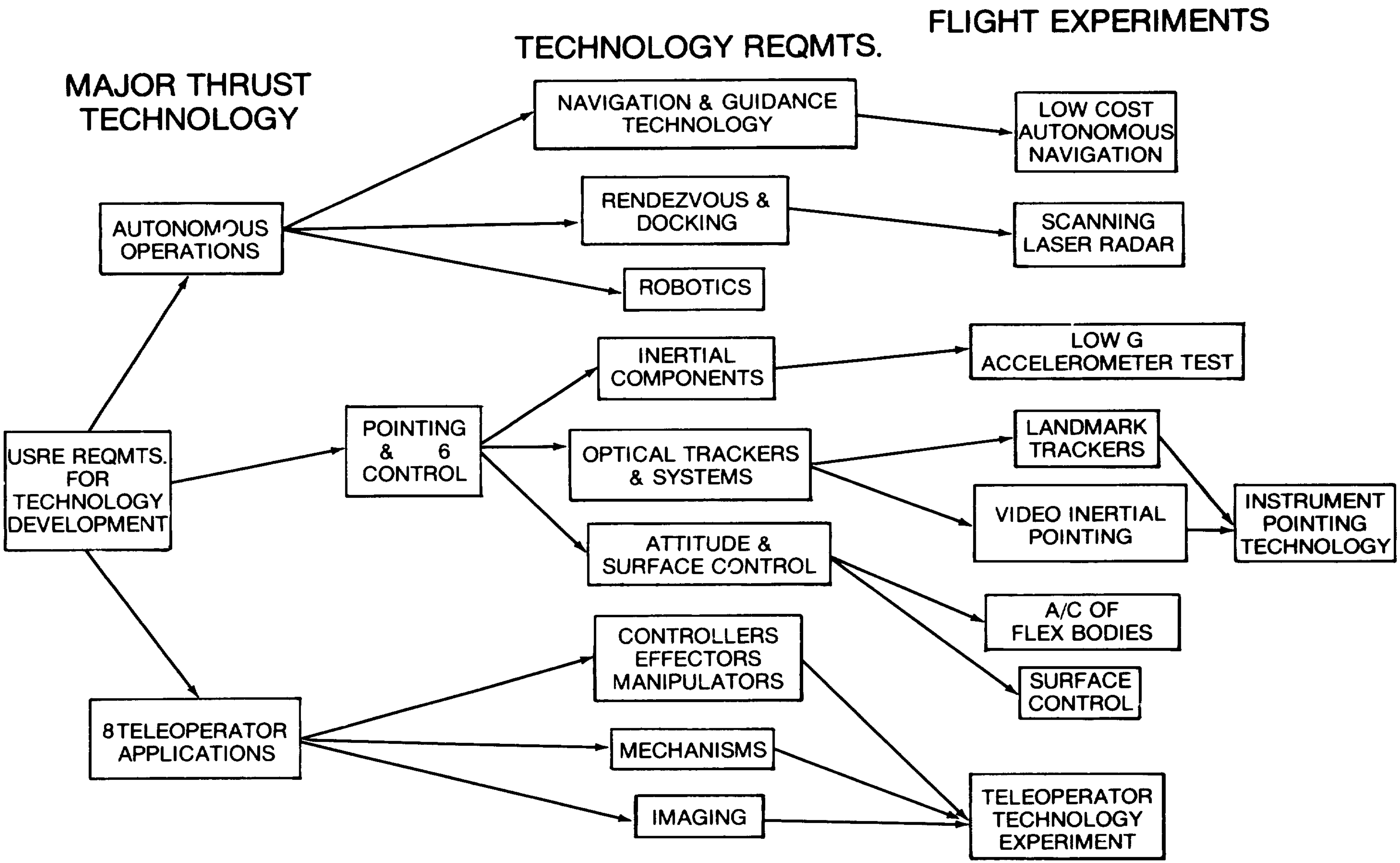
  8— NAVIGATION & GUIDANCE
  16— POINTING & CONTROL SENSORS
  9— POINTING & CONTROL SYSTEMS & COMPONENTS
  14— TELEOPERATORS AND ROBOTICS

* 5 REFERRED TO OTHER GROUPS

* 12 POTENTIAL EXPERIMENTS

  2— NAVIGATION & GUIDANCE
  8— POINTING AND CONTROL
  2— TELEOPERATORS & ROBOTICS

NGC-6



NAVIGATION GUIDANCE & CONTROL

NGC-7
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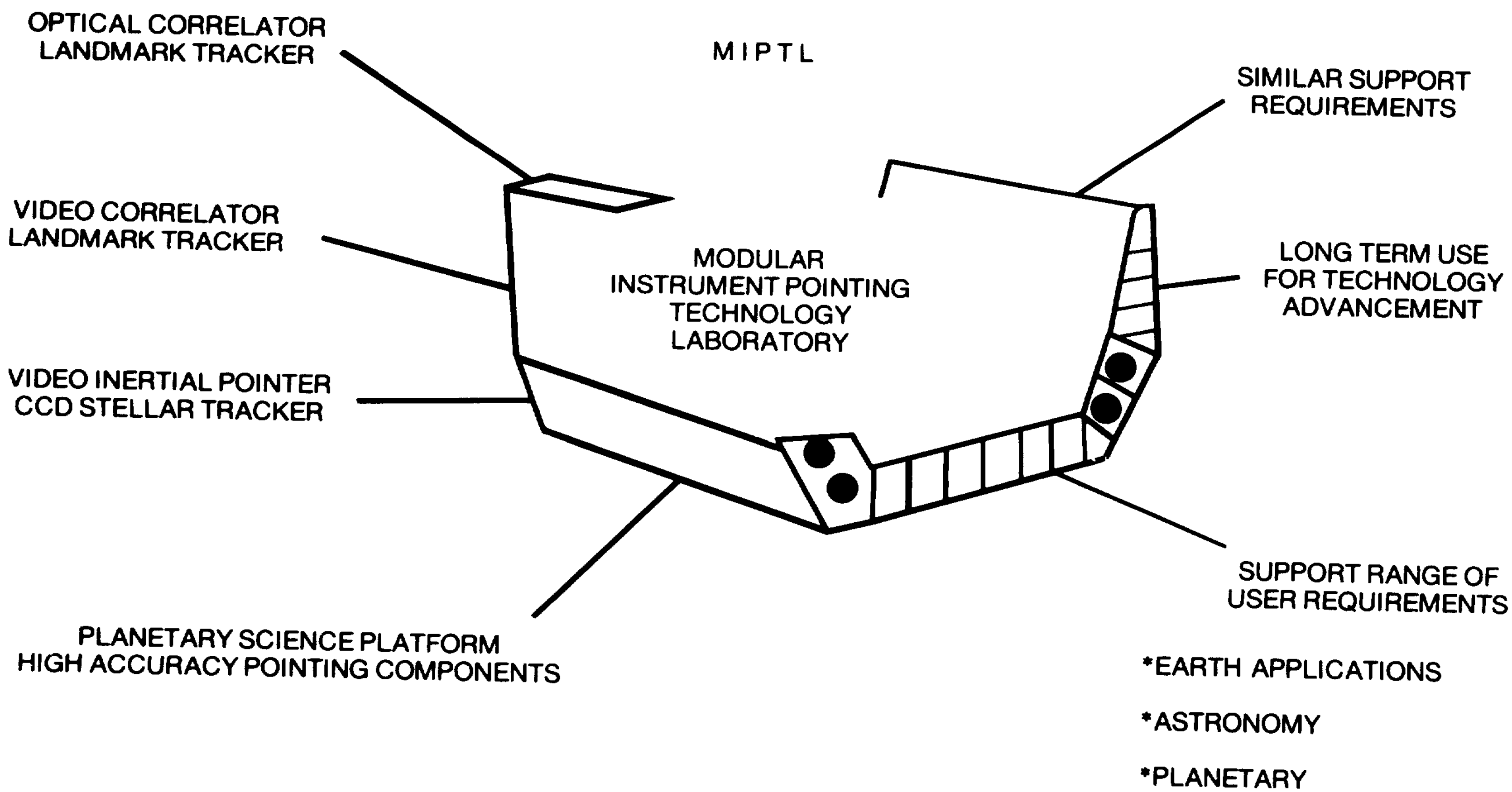
NAVIGATION GUIDANCE & CONTROL

FLIGHT EXPERIMENTS GROUPING



NGC-9

NAVIGATION GUIDANCE & CONTROL

EXAMPLE MIPTL EXPERIMENT

VIDEO INERTIAL POINTING
OAST - AMES

ON GOING EFFORT

*1977 LAB TESTS

PROPOSED EFFORT

*1980 SHUTTLE SYSTEM TEST

USER REQUIREMENTS

*ASTRONOMY TELESCOPE POINTING

*ACCURACY TO < ARC SEC

*MAN-IN-LOOP

BENEFIT OF SHUTTLE EXPERIMENT

*DEMONSTRATE VIP TECHNOLOGY

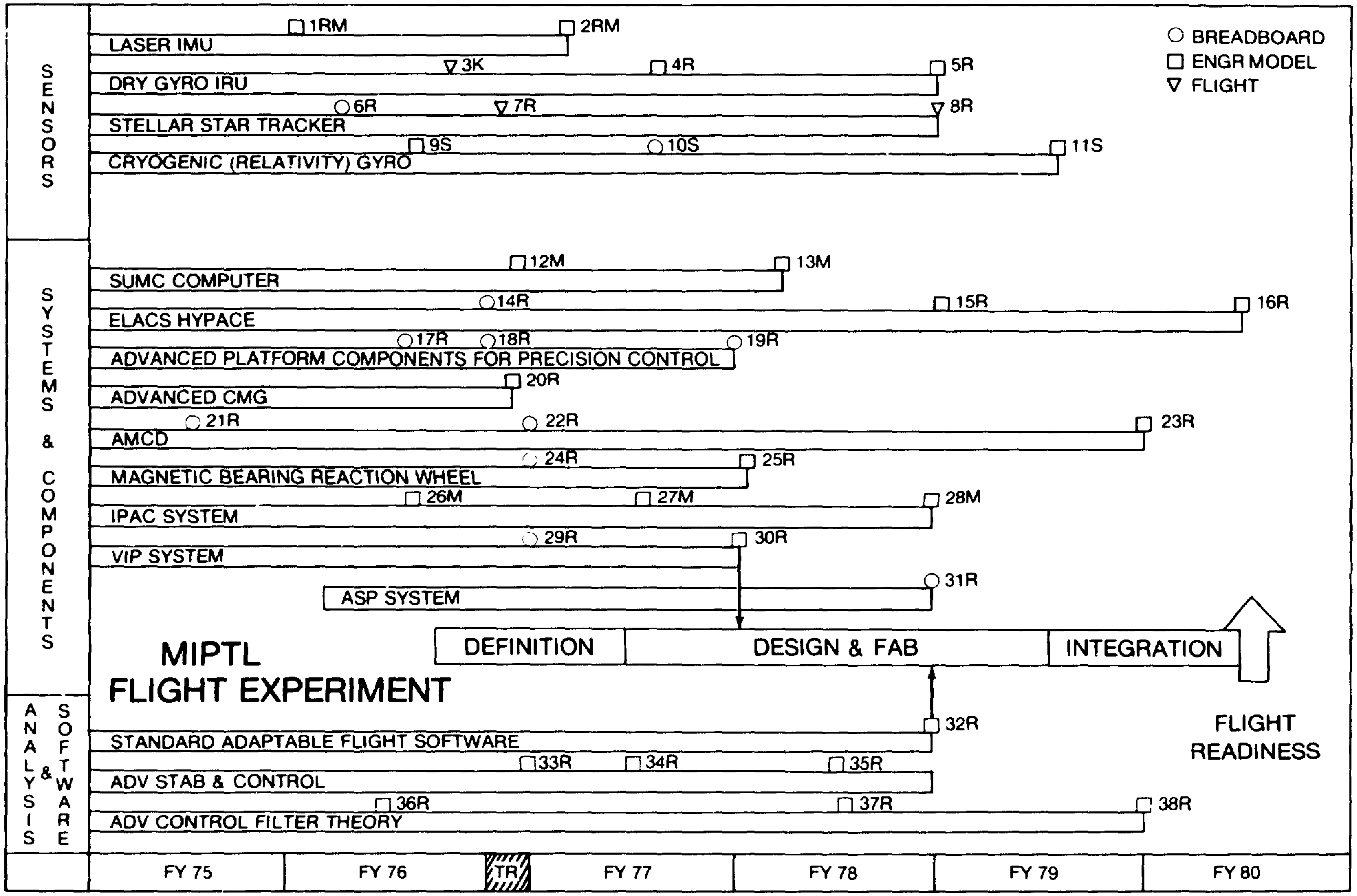
*EVALUATE VIP SYSTEM CONCEPT

*FACTOR FLIGHT EXPERIMENT INTO OPERATIONAL DESIGN

*ENHANCE USER ACCEPTANCE

NGC-10
081575

CONTROL ROADMAP



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NGC-11

NAVIGATION GUIDANCE & CONTROL

CONCLUSIONS

* TECHNOLOGY ADVANCEMENT FOR MAJOR THRUSTS REQUIRE SHUTTLE EXPERIMENTS
* BENEFITS WILL ACCRUE FROM FURTHER INTER-DISCIPLINARY WORK
* ADDITIONAL TECHNOLOGY IDENTIFIED FOR INCLUSION IN CURRENT NASA G N & C PROGRAM

NGC-12